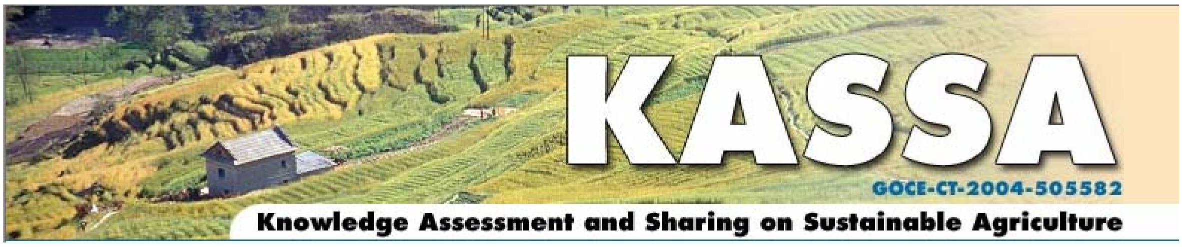


# Deliverable 1.3 - Appendix A2

# Sustainable agriculture research in India

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# I. Introduction (Concepts and Practices)

The main forcing paradigm in India’s agricultural development over the past decades has been to achieve goals of self sufficiency in production of foodgrains in the shortest possible time to obviate dependence on outside world for this critical need. To achieve these goals a strategy has been advocated and adopted which aimed at concentrating public sector efforts and resources in regions with high potential for quick and substantial productivity gains through increased cropping intensity and increased yields. These were areas favored by agro-climatic resource conditions where irrigation facilities already existed or could be developed relatively rapidly. The main elements of this strategy were:

(i) expansion of irrigation coverage, (ii) increased use of key inputs – high yielding varieties of crops, mainly rice and wheat, chemical fertilizers and plant protection chemicals. (iii) expansion and improvement of institutional support (iv) policy regimes favourable to producers of major foodgrain crops. Prevailing use of inputs being low, successive 5-year development plans aimed at achieving targeted production goals though increased use of inputs – spread of high yielding varieties, increased use of chemical fertilizers and pest control chemicals through incentives and promotion programs. This development paradigm was also reflected in overall approach to research. Research was by and large focused to achieve goals of higher productivity by concentrating efforts on a few foodgrain crops, particularly rice and wheat. Increasing cropping intensity and per hectare yield of crops were considered key indicators of research outputs. It is only in the past one decade or so that issues of maintaining and enhancing resource base quality are attracting attention of researchers in view of widespread resource degradation problems in both irrigated and rainfed ecologies. It is becoming increasing apparent that in the vast majority of rainfed crop production systems ability to achieve increased productivity is conditioned by resource base quality. In the well endowed irrigated production systems which have achieved high cropping intensity and high productivity, on the other hand, sustaining high productivity while maintaining the resource base quality and integrity of ecology have emerged as major considerations and a challenge.

This report is an assessment of the comprehensive inventory of the existing knowledge on sustainable agriculture in India. The conventional modes of increasing food production are proving unsustainable as it has led to increasing degradation of natural resources and environmental problems. Efforts have been underway over the past decades to define and develop alternate management strategies which are resource conserving, non-exploitative and which minimize adverse environmental impacts. The main aim of the comprehensive inventory is to compile the knowledge on sustainable agriculture in India. We have included studies, which have preferably been carried over a period time understanding that natural resources improvement is a long -term process.

**Description of Cropping systems and their management**

Research efforts aimed at defining management options, which conserve resources and enhance sustainability of production systems, must therefore be viewed in the context of broad development goals. Management approaches aimed at increasing production and productivity can be broadly discussed under two broad heads: *Irrigated a*nd *Rainfed farming systems.* The geographical focus for the irrigated systems is the north-west India, the region where irrigated rice-wheat cropping system dominates and has significantly contributed to productivity growth of rice and wheat crops in seventies and eighties. The geographical focus of the rainfed systems is the semi-arid tropics region of peninsular India dominated by red and black soils.

*I.1. Irrigated Systems: North-west Indo-Gangetic plains*

Over the past decades Rice-Wheat cropping system has emerged a major production system occupying some 10 million ha in the Indo-Gangetic plains. The Indo-Gangetic plains constitute the most important agricultural region in South Asia. From early 1960s to late 1980s the area under rice-wheat cropping system in the Indian portion of the plains has grown rapidly as have the crop yields resulting in large production gains. The gains were particularly significant in the north-western regions covering the states of Punjab, Haryana and western Uttar Pradesh. The region (north-west) experiences continental monsoonal climate with average annual precipitation of 500 to 750 mm. Nearly 80 percent of the precipitation is received during the rainy season from June to September. In winter months only few showers are received from December to February. Wheat is grown during November to March/early April while rice is grown during the warm humid or sub humid monsoon season (June to October). Traditionally wheat has been cultivated in the region but area under rice increased rapidly in sixties and seventies following availability of suitable varieties. Soils of the region are primarily calcareous deep alluvium with sandy loam to loam texture.

The region is very crucial to the nation with its major contribution to food production. It played a major role of bringing self-sufficiency of food grains in the country. The emergence of the rice-wheat as dominant system was the result of the availability and widespread adoption of high yielding semi-dwarf varieties of rice and wheat (modern germplasm); infrastructural investments especially irrigation systems; and political commitment and policy support. The later two were as important as the first two in the rapid dissemination and adoption of modern technologies and the rapid growth of foodgrains production. (Pingali and Shah, 1999). However, over a period of time as the crop yields and production of these crops have plateaued, increasingly concerns are being voiced regarding several negative biophysical impacts due to exploitation of the natural resources in this region, which has questioned the sustainability of this systems in this region (Hobbs, P. and Morris, M.1996).

***A. Sustainability dimensions of the system***

Several indicators highlight sustainability concerns. Most importantly crop yields are stagnating and there are signs of decline in some areas (Kumar et al, 1998; ICAR, 1998). . Per hectares yields of rice and wheat increased rapidly during seventies and eighties registering over 3percent annual growth in production between 1980-81 and 1995-96. This was significantly higher that the annual population growth rate of 2.14 percent during the eighties. However, annual rates of growth of foodgrains are currently lower than the current population growth rate. This has been a matter of concern. The use of productivity enhancing inputs has reached saturation levels. The area coverage with high yielding varieties is complete; fertilizer use in rice and wheat is optimal. Entire wheat and rice crops in the north-west region are already irrigated. With all the traditional sources of productivity growth having been exhausted future gains will need to come from elsewhere. A number of factors highlight the nature of problem contributing to unsustainability.

- ***Depleting soil fertility:*** Rice-wheat cropping system extracts large amount of mineral nutrients from the soil depending on production level, soil type and whether crop residues are removed or recycled in the soil. Results of several long-term experiments show that removal of P and K by rice-wheat system far exceeds their additions through fertilizers resulting in a net negative balance. As a result while potassium was not routinely recommended in the decades of seventies and eighties, most soils now require its regular application to sustain yields. Similarly the intensity and spread of several secondary and macronutrients deficiencies require regular applications adding to costs and requiring enhanced management expertise. Most studies show that efficiency of utilization of N applied as chemical fertilizers may not exceed fifty percent particularly in rice zones due to volatilization and leaching has serious environmental implications.

A major concern in Rice-wheat system is the declining soil organic matter content and resulting reduced nutrient supplying capacity of soils. These trends have several implications not only for sustained productivity but overall ecosystem functioning (ICAR, 1998).

- ***Increased pest problems*:** Cereals based crop intensification has led to increasing incidence of weed, insect and disease problems. Amongst others, *Phalaris minor*, a growing weed, poses serious problem for wheat and its control has proved extremely difficult due to its developing resistance to the commonly used herbicides. There is evidence that many of the problems will come further accentuate with further intensification as the farmers extend cultivation in summer month and decide to grow limited number of high yielding cultivars.

- ***Declining water resources***: By far the most pressing sustainability concern of the region relates to unsustainable use of water resources. Groundwater is the major source of irrigation in the region. Overexploitation of good quality groundwater for meeting the demands of rice-wheat cropping is resulting in fall of water table. As a result the discharge of shallow tubewells is reduced and energy requirement and pumping costs increases (Jha, 2000). . A large number of shallow tubewells have been rendered non-functional and replaced by submersible pumps, which involves large investment. Groundwater development in most declining water table areas has crossed the safe limit of groundwater exploitation and this is a serious threat to groundwater availability in future (Table 1).

Table 1: Status of Groundwater in North-west India.

| State | No.of Development Blocks | Dark | Gray | White | Overexploited | Groundwater development % |
|---|---|---|---|---|---|---|
| | | Category | | | | |
| | | No | | | | |
| Punjab | 38 | 84 | 16 | 38 | 73 | 94 |
| Haryana | 110 | 50 | 16 | 44 | 25 | 84 |
| Western UP | | | | | | 70 |

Source: *Central Ground Water Board, 2000*

In addition to reduced availability the quality of groundwater is also under threat due to ingress of saline waters from region of saline groundwater. (Abrol 1987). Increasing pollution of surface and groundwater with agro-chemicals is yet another aspect of declining resource quality.

In the relatively more arid agro-ecological regions underlain by poor quality groundwater and where canal water is the primary source of irrigation, rise in groundwater table has lead to water logging and soil salinity problems resulting in widespread resource degradation.

- ***Crop residue burning***: Although the region has achieved high level of mechanization the small turnaround time between rice harvest and wheat sowing being small poses difficulties. To enable timely planting of wheat many farmers harvest rice crop using combines and burn the loose residue to help timely wheat planting (Table 2).

**Table 2 : Residue generation from the North-west region in 1994 (Gg)**

| States | Rice | Wheat | Total |
|---|---|---|---|
| Punjab | 9890 | 20251 | 30141 |
| Haryana | 2810 | 10928 | 13738 |
| Uttar Pradesh | 13284 | 33189 | 46473 |

Burning crop residue releases green house gases and particulate matter in large quantities, deteriorate air quality, results in significant losses of nutrient from the soil and has adverse effect on human health.

Table 3 : Annual national emissions from rice & wheat straw open burning [1] (All in Gg)

| Years | Production | Qt. Of dry residue | CH4 | CO | N2O | NOx |
|---|---|---|---|---|---|---|
| **1994** | 145720 | 150576 | 102 | 2138 | 2.2 | 78 |
| **2000** | 156485 | 162125 | 110 | 2305 | 2.3 | 84 |

total of about 78 and 85 million tons dry rice and wheat straw are generated in India alone in the year 2000(Gupta *et.al*, 2004). Managing crop residues in a way which will promote recycling of nutrients and constitutes to soil organic matter is a critical issue for enhanced system sustainability.

- ***Deterioration of soil physical properties*:** This is a relatively less recognized and appreciated element of unsustainability. The region has achieved high level of mechanization. Extreme rise of tractors and other heavy machinery for intensive tillage, sowing and harvesting operations, declining soil organic matter and excessive soil working to achieve appropriate soil condition for raising crops with contrasting edaphic requirements is leading to gradual deterioration in soil's physical make up. Adverse physical properties are getting increasingly reflected in reduced infiltration rates, development of compacted soil layers, need for excessive and deep tillage to maintain yields (Pingali and Shah, 1999). Farmers often end up in applying higher doses of fertilizers to compensate for adverse effects of physical properties on root growth and crop yields.

In short the farmers of the region are under tremendous pressure and their ability to maintain and enhance livelihood base is getting increasingly constrained by increasing production costs on one hand and declining resource base quality on the other hand. It would seem that most indictors of systems unsustainability are interrelated and any effort to achieve enhanced sustainability must identify the key factors driving unsustainability. It is further apparent that rice-wheat cropping system has evolved in response to pressing need to achieve short term goals of increasing foodgrain production over a short period facilitated by policy regimes which favoured unsustainable resource use. It would , therefore appear that efforts to promote sustainable agriculture in this region must aim at, amongst their objectives, alternate cropping strategies which promote sustainable resource use and a reversal of resource degradation processes.

### *B. R& D effort as alternatives to cope with the above problems*

Management approaches that have been researched to enhance sustainability of this production system can be broadly grouped as follows:

### 1. Inclusion of a green manure crop in the cropping system

A good amount of experimentation effort has aimed at evaluating the role/ benefits of growing a green manure (e.g. Sesbania) or a short duration grain legume crop (e.g. Mungbean) (Aulakh et al, 1998, 2000). The objective of this research was to explore (1) if and how much saving in the use of nitrogenous fertilizers can be affected by incorporating a green manure crop before planting rice without sacrificing yield and (2) what effect this practice has on the organic matter status of soils. Results of most studies show that while green manuring substituted for a significant fraction (35 to 40 percent) of chemical N fertilizer needs of the crop grown immediately, thereafter the practice had no beneficial efforts in terms of carbon build up. The residual effect of mungbean and most of the legume green manures is short lived because of their small C:N ratio and low lignin contents resulting in rapid decomposition The residual effect of mungbean and most of the legume green manures is short lived because of their small C:N ratio and low lignin content resulting in their rapid decomposition. The practice has not come to be widely adopted due to a combination of factors like, labour and time involved for growing, harvesting and incorporating the crop and high water requirement of the green manure crop which is grown in the peak summer months after wheat harvest in April.

**2. Integrated use of inorganic and organic nutrient sources**

The main aim of many on-farm long-term experiments, which were initiated in seventies and eighties, has been to evaluate the role of integrated use of chemical fertilizers and organics (chiefly farmyard manure) on crop productivity. The underlying objective of these studies was to assess the nutrient substitution value of organics with respect to costly inorganic fertilizers for maximizing crop yields. The effect of Farm Yard Manure (FYM)(composted material) on soil organic matter was variable and tended to be maintained or slightly enhanced when large quantities (15 t/ha) were incorporated annually. Combined use of inorganic fertilizers and organics invariably helped maintain overall fertility and yields. Application of large quantities of FYM is not feasible because such qualities are just not available (Singh Yadvinder, Bijay Singh, J.K. Ladha, C.S. Khind, R.K. Gupta, O.P. Meelu, and Pasuquin (2004). Also little effort was made to understand and build farmers' perspective, how they perceived the role of organics and in what way they were arriving at a decision to use limited quantities of organics available with them.

**3. Crop residue recycling and as Mulching**

In high productivity rice-wheat cropping system large amounts of crop residues, up to 5 to 6 t/ha. each of rice and wheat are available and their optimal management has attracted considerable on farm experimental effort. Traditionally wheat and rice straws are removed from the fields for use as cattle feed and for other purposes e.g. livestock bedding, fuel etc. However with increasing use of combine harvesters farmers prefer to burn large quantities of residues left in the field as these interfere with tillage and seeding operations for the next crop. Burning residues contributes to intense air pollution with accompanying health hazards apart from losses of organic matter and nutrients. Research efforts to define management strategies have focused on studying the long-term effects of soil incorporation of residues on agronomic response and soil properties. Most studies reveal that with limited time available for decomposition of incorporated rice straw, subsequent crop yields were invariably lower chiefly due to nitrogen immobilization (Aulakh *et.al*, 2001). This would imply that farmers have to use additional doses of nitrogen fertilizers in order to achieve the yield levels equivalent to the yield obtained when residues were not incorporated. Over a longer term, most of these studies point out the beneficial effect of incorporating residues in terms of maintaining organic matter although, yields tended to remain slightly lower (Beri, .1992, 1995) Enhancing the decomposition of residues by additional application of inorganic N or cellulytic bacteria could alleviate some of these problems, but would entail additional costs.

Growing and incorporating a green manure crop (e.g. Sesbania) or weed (e.g. Lantana) along with wheat straw enhanced decomposition of crop residue and increased yields (Bhushan & Sharma, 2002). However many of these practices have not found favour with farmers for reasons that they do not see clear benefits of alternate management options in terms of enhanced incomes. Crop residues or other organics as mulch in experimental plots were invariably reported to enhance yields under rainfed (discussed in the next section) and limited irrigation conditions chiefly through conservation and increased availability of soil water. Again these practices have not found wide acceptance by the farmers.

## 4. Reduced/zero Tillage and land shaping

Time of sowing/ planting is a key factor in optimizing cropping system productivity. However, farmers are often forced to delay sowing of wheat crop following harvest of rice. This is because in their efforts to increase rice production by adopting longer-duration rice varieties invariably wheat sowing is delayed significantly reducing the yield potential and efficiency of inputs. To overcome this problem, efforts have been underway for over a decade to develop, standardize and promote equipment for seeding wheat following rice harvesting without preparatory irrigation and tillage varieties under the aegis of Rice-Wheat consortium. Planting wheat on beds (in bed–furrow system)and land leveling using laser aided equipment is yet another innovation which the farmers are adopting increasingly as way to achieve enhanced productivity and efficiency of inputs.

In rice-wheat cropping system rice is grown under submerged conditions which requires the soil to be puddled each time. Puddling soil is an energy intensive process which causes structural breakdown. Thus, adoption of zero tillage in wheat, though beneficial is unlikely to bring about any significant improvements in soil quality in rice-wheat cropping system. Similarly, there is sufficient evidence to show that zero tillage, by itself, is not likely to contribute to significant improvements in soil quality.

Amongst the alternatives the conventional agriculture, zero-tillage technology to sow wheat crop following harvest of rice has found acceptance by the farmers and is spreading rapidly over large areas. According to estimates of Rice-wheat consortium currently zero –tillage for wheat is being adopted for over one- million hectares area. Zero-tillage has enabled the farmers to reduce cost of wheat production and increase yields by 10 to 15% over conventional tillage by facilitating timeliness in planting i.e., 1 to 2 weeks earlier planting.

Other benefits which have been cited by the farmers include: reduction in time required per irrigation and reduced number of irrigation due to mulching effects of crop residues left on the soil. A significant feature in adoption of zero-tillage technology is that all categories of farmers (based on size of holding) are adopting zero-tillage and its advantages are well understood. Farmers perception of benefits from zero-tillage include: savings on cost of production enabling higher profits savings of irrigation water, particularly in the first irrigation, a reduction in the *Phalaris minor* weed population in wheat and reduced weedicides costs on this account.

Development and spread of zero-tillage technology has important lessons for future strategies to develop and spread conservation agriculture practices. An important element in rapid adoption and spread of technology was the ability of scientists to work closely with farmers and private sector machinery manufacturers enabling quick feedback and refinements in machinery which removed important bottlenecks in large scale adoption. Further active participation of manufacturers has greatly improved the availability of zero-till drill accelerating the adoption process. These institutional innovations will be critical I our future efforts to develop and promote conservation agriculture technologies.

The development and adoption of zero-tillage and associated innovative land and water management systems (e.g. bed planting) provide a unique opportunity to introduce new crops and cropping systems as alternate to rice-wheat system. Future efforts ill need to capitalize on these opportunities to accelerate the diversification o to cropping system through a comprehensive strategy which includes policy and market analyses for research and development to achieve greater system diversification.

## C. Driving forces and Constraints to dissemination of alternatives to Conventional Agriculture

Driving forces leading to development and rapid adoption of alternate conservation technologies must be attributed to the congruence of technological interventions and participatory operational approaches facilitated by the rice and wheat consortium over the past decade or so. Some of the emerging sustainability concerns and constraints of this system have indeed become the principle driving force for development and dissemination of alternatives in the form of resource conserving technologies (RCTs) to maintain the sustainability of rice-wheat cropping system in this region. Major driving forces leading to development and transfer of alternatives to conventional agriculture include:

- Stagnating productivity and indications of yields declines in experimental plots where inputs were held constant.
- Farmer’s perception of the need to spend more on inputs to maintain yields and experimental evidences of declining factor productivity.
- Increasing intensity of the problems of weed control particularly of *Phalaris minor*. Due to development of resistance to commonly used herbicide.
- Increasing concerns related to declining water tables in large areas leading to increased pumping costs replacement of shallow tubewells with deep tubewells at high cost.
- Opportunity to enhance yields through early/timely planting of wheat following the harvest of long duration high yielding rice cultivars.
- Development and modification of critical implements (zero-till wheat planter, lased aided equipment for land leveling, bed/furrow former) through on-farm testing, rapid feedback of farmers response to scientists, validation of prototypes with active involvement of private sector machinery manufacturers etc..
- Opportunity for innovative farmers and scientists to experiment together to develop and test farm implements, test new planting techniques etc., in contrast to the usual approach to wait for a technology to be perfected by researchers and extentionists before it is recommended for adoption.

- Innovative approaches adopted by farmers to supplement their income while being instrumental in spread of new technologies. For example, farmers providing contractual services to use of new equipment like laser leveler, zero-till drill etc.

Some of the important constraints to adoption and spread of new technologies include:

- The new technologies e.g. zero-tillage, bed planting, residue management have to be seen in the perspective of entire system. Zero-tillage, while enables early planting of wheat also affects water management needs and options crop residues in zero-till system also affect nutrient and water management needs. Understanding the dynamics of physical, chemical and biological changes would be important to form a basis for developing and promoting continuously improved management approaches. This will call for new way of technology generation, involving multidisciplinary teams of scientists in contrast to hither to discipline based approaches in developing and promoting technologies.
- Conservation Agriculture technologies are knowledge intensive. Our present extension systems are not geared to be interactive with scientists on one hand and farmers on the other. As new technologies get increasing acceptance there will be need to adopt more innovative approaches in building scientists, farmers extension linkages.
- Prevailing policy regimes favoring only a few crops can be a disincentive to adoption and spread of alternatives to conventional agriculture.
- Rapid feedback of farmers response to engineers, validation of prototypes with active involvement of private sector machinery manufacturers etc.

**I.2. Rainfed Production System**

According to recent statistics, India's net irrigated area totals 53 million hectares. With more than one crop irrigated per year on some of the land, the gross irrigated area is 72 million ha. This means that nearly 115 million ha. i.e., nearing 60 percent of the gross cropped area is farmed under rainfed conditions. Rainfed farming accounts for nearly 35 percent of total foodgrain production. Nearly 80% of maize and 95 percent of pearl millet and of sorghum are produced under purely rainfed conditions as are some 75 percent of oilseeds, 90 percent of pulses and bulk of cotton, fuel wood and fodder.

Rainfall regime and soil characteristics are the key determinants of rainfed cropping potential and India's unirrigated areas differ widely with respect to both. Significant aberrations from 'normal' rainfall pattern are frequent with respect to onset, continuity, intensity, volume and withdrawal of monsoon rains. Uncertainties associated with monsoonal observations pose significant farming risks and therefore, sharply limit resource poor farmers willingness to adopt cropping practices which may prove costly.

Nearly 30 percent of India's rainfed areas are arid or semi arid (rainfall <750 mm ; arid < 500 mm) the remaining is about equally divided into areas with medium (sub humid) (750 mm to 1150 mm) and high (humid) (> 1150mm) precipitation. Particularly, in the arid and semi-arid areas there is considerable uncertainty about timing and volume of rainfall in any given year. In the high rainfall regions rainfall is very intense during 3 to 4 months of the rainy season making land and water management extremely difficult. From the context of conservation agriculture, therefore, medium rainfall and to some extent semi arid regions would seem to hold considerable promise.

***A. Soils***

Among the soil groups found in India's rainfed areas five are predominant: Red soils (Alfisols), Black soils (vertisols), Alluvial soils, Submontane soils and Desert soils. The bulk of alluvial soils currently farmed under rainfed conditions are found in riverrine plains of northern India and major river valleys and deltas of peninsular India and would be eventually irrigated from surface or groundwater.

*Red Soils (Alfisols)* cover about 72 million ha. and rainfall in red soil areas ranges from 750 to 2000 mm per annum and constitute nearly one-third land area under the SAT region. These soils are highly weathered, have low clay (10 to 20 percent) and organic matter content. Despite their importance for food production for the growing population of the region, their productivity has remained low and unstable owing to climate and soil related constrains. The climate related constrains include short rainy season, variability in timing and amount of rainfall, high intensity rains resulting in high runoff and soil erosion, high temperatures and high evaporation rates. Soil properties further aggravate the adverse impact of climate related constraints. Low soil strength of saturated soils leads to surface sealing and crusting under rain-drop impact, renders soils highly erodible and reduced plant available water capacity. High strength of dry soil makes preparation of seed bed very difficult until rains soften the soil. Combination of climate and soil related constrains leads to a narrow 'window of opportunity' when crops can be successfully established. Red soils have considerable agronomic potential. At present they are cropped mainly in the *kharif* (rainy season).

*Black soils (Vertisols)* occur over some 64 million ha. of which only about 24 million ha. are cropped. Annual precipitation in black soil regions ranges from 500 to 1500 mm. Compared to red soils, black soils are deeper (from less than 30 cm to 90 cm or more), have higher clay content (30 to 70 percent) and hold more water than red soils. Soils are prone to runoff and are highly erodible. On *shallow black soils* only *kharif* cropping is possible because of insufficient soil moisture to sustain a crop on the *rabi* season. In low rainfall deep black soils areas where soil moisture is insufficient to support two successive crops, *kharif* fallowing is practiced and a *rabi* crop grown as moisture already in the soil is less risky than a kharif crop under uncertain rainfall conditions.

*Deep black soil* areas with dependable rainfall (750 to 1250 mm) which cover extensive areas in Madhya Pradesh, Andhra Pradesh, Karnataka and Maharastra have the widest gap between actual and potential crop yields of any rainfed farming region. When wetted deep vertisols swell and become very sticky but, shrink rapidly when they dry out leaving large clods and deep and wide fissures. With traditional farmer implements and uncertain rainfall conditions timely cultivation is very difficult. Consequently most farmers leave the land fallow during *kharif* and raise instead a *rabi* crop on residual soil moisture. *Kharif* fallowing means, however, that 3 to 4 month of cropping season are lost with runoff and soil erosion area accelerated.

*Submontane soils* are prevalent in hill and foot hill regions which receive 750 to 2000 mm rain annually and have a good potential for agriculture. Controlling runoff and erosion to protect against dry season moisture stress is particularly important.

*Desert soils* are light textured sandy soils occurring mainly in the western India and have low moisture retention capacity and are situated in region with low rainfall and are subject to wind erosion.

### *B. Major Cropping Pattern in Rainfed Area*

Following table gives the major cropping pattern being adopted by farmer in different rainfall zones.

Farmers in the unirrigated areas generally are the poorest in the country and face formidable technical and socio-economic constrains. Soils in many rainfed areas are characterized by poor physical conditions, water holding capacity and fertility and are often affected by serious drainage problems. There are considerable variations in agricultural systems of rainfed areas, characteristically they are subsistence oriented producing essential food and fodder for local consumption. There are exceptions, however, where cash crops such as groundnut and cotton are important. Crop yields are low and unstable due to rainfall-related constrains and continued adherence to traditional management practices.

Table 4: Cropping Pattern in the rainfed area

| Annual Rainfall Zone | Rainy Season | Post-rainy Season |
|---|---|---|
| Less than 500 mm | Pearl Millet, Moth Bean Cluster Bean, Mung Bean Sorghum (fodder) | - |
| 500-750 mm | Pearl Millet, Sorghum Caster | - |
| | - | Chickpea,Sorghum, Mustard |
| | Mung Bean, Sorgum (fodder) | Mustard |
| 750-1,000 mm | Ragi, Cowpea + Ragi | - |
| | - | Wheat, Chickpea |
| | Maize | Wheat |
| | Sorghum | Chickpea |
| | Sorghum | Safflower |
| | Soyabean | - |
| | (Sorghum/Maize/Pearl Millet) + Pigeonpea | - |
| More than 1000 mm | Rice | Wheat/Chickpea/ Mustard/Groundnut/ Mungbean/Urd-Bean Sesamum/ Linseed |

In many arid and semi arid regions, animal husbandry accounts for a major fraction of total farm income. For this reason choice of crops and varieties is primarily determined by the expected yield and quality of fodder. Despite widespread preference for traditional varieties a large portion of livestock feed requirement is obtained from public grazing lands. Heavy grazing combined with poor cultivation practices reduce land's moisture absorption capacity and much of the rainfall is lost as erosive runoff. High runoff also means low groundwater recharge and therefore reduced groundwater irrigation potential.

Agro-technological production constrains faced by vast majority of farmers of rainfed areas are primarily responsible for their low incomes and living standards. To successfully cope up with varied agroclimatic, physical and biological constrains in rainfed area, technological and management improvement are essential. Amongst key weaknesses the following appear most critical.

- Need for conservation practices that would reduce runoff and soil erosion & provide improved surface drainage and better soil fertility, particularly on black soils.
- Inadequate attention to timely and efficient field operations and availability of appropriate implements.
- Mismatch between traditional crop varieties and prevailing rainfall pattern.
- Inadequate control of disease pests and weeds.

## C. Alternatives to conventional agriculture and constrains to adoption

In the past, two separate thrusts have been pursued in technology generation and promotion aimed at conserving more water for crop use: one aimed at increasing moisture stored within the soil profile, the other at runoff collection and storage for subsequent use. Significant efforts in the past have focused mostly on the second approach-construction of farm ponds and community reservoirs and propagation of 'life-saving' irrigation during critical periods of crop growth. This approach continues to be emphasized in most of the watershed based development programs. Efforts to improve the productivity of rainfed cropping must, above all, seek to reduce the risk of crop failures. This depends vitally upon, first, effective *in situ* moisture conservation and second, availability of crop cultivars adapted to prevailing agroclimatic situations. Till seventies and mid eighties research efforts were mainly focused on plant breeding while, the crucial need for *in situ* moisture conservation largely received a low priority. Soil management /tillage options to conserve rainwater have generally emphasized early (or off season) ploughing and harrowing for rainfall retention and penetration and to create a soil mulch. More specific recommendations for different soil and rainfall conditions involved various techniques to modify surface configuration of land: examples include: dead furrows at 3-6 m intervals for low rainfall red soils with dense subsoils.

- Raised bed/ sunken bed technology for fine textured, slowly permeable soils in regions receiving more than 1000 mm rainfall. It involves construction of 20 cm high and

3 m wide raised beds for upland crops adjacent to 20 cm deep and 6 m wide sunken beds for rice cultivation.

- Seedling mulch technology: Developed for pearl millet and cotton cultivation on soils susceptible to crust formation, the technology involves application of farmyard manure or crop residues on the seed lines immediately after sowing.

- Crop residue cycling: The technology was developed for sorghum, maize, pearl millet and groundnut cultivation on red sandy loam soils which are prone to crusting and become very hard when dry. It involves incorporating powdered groundnut shells or paddy husk in soil about one month prior to sowing.

- Broad bed and furrow (BBF) Cultivation: The technology was developed by ICRISAT for deep black soil areas with medium to high rainfall where the water holding capacity of soils is sufficient to raise two crops per year without irrigation but where drainage is a major problem and interferes with tillage operations. Essentially it involves preparing raised planting beds of about 100 cm width alternating with furrows of 45 width at a gradient of 0.2 to 0.4 percent depending on soil type.

Although, many of these technologies have been demonstrated to increase crop yields, adoption by the farmers has not been widespread because the technologies are not low cost and returns are insufficient for farmers to take the risk. Another major weakness has been that agronomic and soil and water conservation thrust has been pursued largely in isolation from each other. As a consequence agronomists and conservation specialists have developed little appreciation of mutuality of each others' concern, and there has been limited integration of their efforts in the field. However in recent years, the emphasis on watershed based planning and implementation of efforts to improve the conditions of rainfed farming has had considerable positive effect in bringing staff from different disciplines together in a collaborative undertaking. This has greatly helped improve each side's understanding of other's potential contribution to achieve overall goals.

## D. Conservation tillage/mulch based approaches

Much of the efforts aimed at improving the productivity of rainfed areas have aimed at defining primary and secondary tillage options (dry season tillage, dry tillage, manipulating surface configuration etc.) for increased rainwater retention and control of weeds. Tillage based approaches though temporarily increase soil porosity, help retain initial rainfall spells and therefore help increase crop yields marginally, this appears only a short term remedy for physical problems and indeed aggravate the problems in the long term. Tillage creates a cycle of decline in which tillage needs increase the need for more tillage to maintain infiltration capacity. Studies at ICRISAT clearly suggest that

(i) Surface crust is a major factor that limits infiltration.

(ii) Conventional practice of mechanical tillage to break the crust and improve infiltration has little long-term impact in increasing infiltration.

(iii) Amendments including crop residue offer a sustainable way to improve infiltration rates and productivity but is constrained by the availability of the material.

(iv) There is need to develop alternative method to improve organic matter content and structural stability of soils to maintain high infiltration capacity.

During the past, about decade and a half a number of studies have evaluated the 'Conservation tillage' techniques as an alternate to conventional tillage methods. Conservation tillage essentially implies crop residues being left in soil surface to protect it against the impact of torrential rains and use of no tillage and use of no till planting equipment to allow sowing through trash. These studies brought out that runoff from no-till system without any plant or straw cover was controlled by surface crust and showed little change overtime. Straw mulch consistently reduced runoff and soil erosion compared to bare plots and that organic residues in no till system could significantly increase the amount of water available for crops. Runoff from tilled plots, which was reduced sharply after tillage operations reverted back to that from untilled plots after a few storms suggesting structural instability leading to formation of surface crust. Benefits of residues on soil surface came through reduced direct impact of raindrops on soil particles, reduced velocity of runoff providing greater opportunity time for infiltration and increased biological activity. Crop yields improved significantly in mulch based systems as also in treatments which, included rotation of crops with perennials. Zero tillage in absence of crop residues was ineffective in reducing runoff in black soils but amendments like, phosphogypsum and crop residues were helpful in reducing runoff, soil loss and improved infiltration. These studies show that mulch based management systems when combined with zero tillage and appropriate land configuration hold a promise for significant improvement in crop yields through greatly enhanced *in situ* rainwater conservation and soil quality. Results of on- farm studies not withstanding, there has been no serious effort to promote adoption of conservation tillage (zero tillage and surface managed crop residues) in rainfed areas. One reason is the premise that crop residues being important as animal feed, farmers will not be willing to use them as mulch. It would appear important that knowledge and value of conservation tillage and associated benefits are widely shared and region/ location specific technological options evolved for varying soil agro-climatic and farming situations and this must be done working closely and in collaboration with farming communities.

### III. Significance and impact of the results

India's agricultural development efforts over the past four decades have largely concentrated in achieving goals of self sufficiency in production of food grains, mainly rice and wheat. Increasing production and productivity through increased inputs use was considered as main route to achieve these goals. The main strategy adopted was to expand irrigated area, spread high yielding cultivars of selected crops and promote 'packages of practices' developed by research institutions for adoption by farmers. Increases in irrigated acreage, coverage by high yielding varieties, use of chemical fertilizers and plant protection chemicals, increases in per hectares yield and total production were the main criteria of achieving development objectives. In tune with development goals the efforts of scientific community were focused on ways of achieving higher productivity of selected crops with emphasis on reducing purchased inputs. In this process relatively little attention was devoted to understanding the impact of agricultural practices on the status and dynamics of resource base quality. In this study knowledge base for sustainable agriculture has been reviewed in respect of two major production systems: irrigated and rainfed.

Rice-wheat based cropping system has emerged as a major production system in the irrigated areas. Emergence of this system is largely due to availability of high yielding crop cultivars which could be grown in sequence and a policy regime which favoured growing these two crops. From agro-ecological considerations, rice crop is not ideally suited for low rainfall situation of north-west. Also wheat and rice require contrasting edaphic conditions for optimal performance yet farmers have preferred this system for the reasons that under the prevailing policy regime no other cropping system is as remunerative. Thus, while the sustainability of the system itself is questionable much of the research effort was devoted to defining practices that would enhance the sustainability of the given system, particularly in terms of system productivity and returns. Nitrogenous fertilizers being a major costly input, several studies evaluated the role of organics in cutting down the dosage of fertilizers application. Management of crop residues, particularly rice straw has drawn particular attention since wheat straw is mostly used as cattle feed and farmers prefer to burn the rice straw to enable timely planting of wheat for optimum yields. Results of several on-farm studies has been interpreted to show that in the long run rice straw incorporation results in improving soil carbon status. The practice has not found favor because of the need to apply extra nitrogen (to take care of N immobilization) for maintaining yields. Benefits of the other practices in the form of mulching, growing green manure crops or short term legumes are well known but there has been little effort to take them in a big way. In their effort to obtain high production levels farmers are increasingly tempted to grow longer duration rice varieties which delay planting of wheat adversely affecting the yield. Zero tillage and associated need for better residue management has emerged as an effective response to achieving higher system productivity by saving on the time and energy required for field preparation and in enhancing use efficiency of inputs. The practice is being rapidly adopted by farmers and along with bed planting, laser land leveling and other innovations would appear to be paving a way for no tillage and surface residue management system for diversified cropping system which is the emerging need.

Most of adoption and impact studies related to alternative system of agriculture still concentrate to production parameters alone as in most of the conventional agricultural evaluation studies. They rarely include their impact on natural resources, its quality, processes/relationships that enable the success or failure of the study. These evaluation or socio- economic studies should be part of the main study and not done as a separate study, which is done after the adoption is over or at the end of research process. Adoption of conservation agriculture systems over large areas is a way to improved ecological foundation, which form a basis for Sustainable Agriculture. It is therefore, important that evaluation of conservation agriculture takes into account the impact of the system on overall environmental performance or improvement in the natural resources. Thus, research and development for Conservation Agriculture will call for several innovative features to address the challenges.

Conservation Agriculture offers an opportunity for arresting and reversing the downward spiral of resource degradation, diminishing factor productivity and decreasing cultivation costs making agriculture more resource use-efficient, competitive and sustainable. While R&D effort over the past decade have contributed to increasing farmer acceptance of zero-tillage for wheat in rice-wheat cropping system, this has raised a number of institutional, technological and policy related questions related to technology generation, adaptation and further improvement, which must be addressed if conservation agriculture practices have to be adopted on a sustained basis. Conservation Agriculture poses a challenge both for the scientific community and the farmers to overcome the past mindset and explore the opportunities that conservation agriculture offers for natural resources improvement. Conservation agriculture is now considered a *route to sustainable agriculture.* Spread of conservation agriculture, therefore will call for a greatly strengthened research and linked development efforts.

- Since the policy imperatives in terms of price procurement, distribution etc., favoured the two foodgrain crops, there was little scope for crops alternative to rice and Wheat. In India, and other developing countries a well articulated policy goal for livelihood security and rural development must now replace the short term focused food security policy based on cereal production. A factor price support followed by mandatory procurement for the crops alternative to rice and wheat that do not overexploit natural resources and enable policy mechanism and environment for other crops should be stressed upon. Emphasis should be on selecting and developing crops and varieties which result in saving of inputs like, water, electricity, fertilizers etc.,.

- Although significant successful efforts have been made in developing and promoting machinery for seeding wheat in no till system, successful adoption of conservation agriculture systems will call for greatly accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences, permanent bed and furrow planting systems, harvesting operations to manage crop residues etc.

- Conservation agriculture systems represent a major departure from the past way of doing things. This implies that the whole range of practices including planting and harvesting, water and nutrient management, diseases and pest control etc. need to be evolved, evaluated and matched in the context of new systems.

- Managing Conservation agriculture systems will be highly demanding in terms of knowledge base. This will call for greatly enhanced capacity of scientists to address problems from a systems perspective, be able to work in close partnerships with farmers and other stakeholders and strengthened knowledge and information sharing mechanisms.

- Adaptive strategies for conservation agriculture will be site specific and will call for initiation of R&D effort under a range of situations which aim at exploring multiple benefits by building context specific partnerships to address key livelihood issues. Learning process across the sites will be a powerful way of understanding which technologies and why they are effective in a particular set of situations. This will greatly accelerate building a knowledge base for sustainable resource management. Developing and promoting networking to share information among partners will be critical in advancing spread and continuous improvement of conservation agriculture systems

- Promoting conservation agriculture will call for moving away from the conventional compartmentalized and hierarchical arrangement of research that generates and perfects technologies, extension that delivers it and farmers who passively adopt it. All the stakeholders involved would need to be brought together on a common platform to conceive end-to-end strategies. Institutionalizing the role of research, extension and farmers in such a way that the partnership among these stakeholders might be strengthened right from the beginning of the project, and building up sense or enabling of ownership among them.

- Conservation agriculture offers opportunities for diversified cropping systems in different agro-ecoregions. Developing, improving and standardizing equipment for seeding, fertilizer placement and harvesting ensuring minimum soil disturbances in residue managements for different edaphic condition will be key to success of conservation agriculture systems. For many situations, for example in hilly tracts, for small land holder's bullock drawn equipment will have greater relevance. Ensuring quality and availability of equipment through appropriate incentives will be important.

- Impact of conservation agriculture technologies on resource quality and environment is slow and significant changes may show up only over a period of time. There is a need to set up long term monitoring sites in representative agro-ecological situations to monitor resource quality, ecology and productivity with a view to continuously improve management options for sustained improvements. Evaluation and impact of conservation agriculture practices therefore needs a longer term and broader perspective, which goes beyond yield increase studies.

- Conservation agriculture practices i.e., no tillage and surface maintained crop residues set in processes which initiate changes in soil physical, chemical and biological properties which in turn affect root growth and crop yield. Understanding the dynamics of these changes and interactions between physical, chemical and biological phases is basic to developing improved soil, water and nutrients management strategies. Similarly understanding the dynamics of qualitative and quantitative changes in soil biodiversity (flora and fauna), diseases and pest causing organisms including weeds in relation to altered management practices is fundamental to evolve control measures which involve minimum use of environmentally harmful chemicals.

- Conservation agriculture technologies bring about significant changes in the plant growing microenvironment. These include changes in moisture regimes, root environment, emergence of new pathogen populations and shifts in insect-pest scenario etc. The requirements of plant type suited to the new environment and to meet specific mechanization needs could be different. There is need to develop complementary crop improvement programme aimed at population which are better suited to the new systems. Farmer-participation research approaches would appear promising for identifying and developing crop varieties suiting specific environments or locations.

- Accelerated development and adoption of conservation agriculture technologies will call for greatly strengthened monitoring and evaluation along with policy research.

Understanding constraints in adoption and putting in place appropriate incentive for adopting conservation agriculture systems will be important. This will call for considerable strengthening of social science research.

Institutional mechanisms are required to ensure that conservation agriculture is seen as a concept beyond agriculture and promote it as a theme ensuring effective linkages between R&D activities. Conservation agriculture must aim at broad livelihood strategies and move towards forming conservation villages, with appropriate agribusiness strategies to increase employment in areas where it is adapted. However, caution must be taken to avoid blanket adoption of conservation agriculture just everywhere; it should be site specific and need based. Conservation Agriculture implies a radical change from traditional agriculture. There is a need for policy analyses to understand how conservation technologies integrate with other technologies, policy instruments and institutional arrangement that promote or deter conservation agriculture. It is therefore a challenge both for the scientific community and the farmers to overcome the past mindset and explore the opportunities that conservation agriculture offers for sustained agriculture. Conservation agriculture is now considered a route to sustainable agriculture. Spread of conservation agriculture, therefore will call for a greatly strengthened research and linked development efforts.

## III. Conclusions and Proposals

Indian agriculture is moving from a phase of concerns for self-sufficiency in food production to broader societal goals related to livelihoods, sustainability, environment, resource base improvement etc. While we have been successful in achieving the goals of self-sufficiency in food production by increasing production and productivity of limited foodgrain crops in well endowed irrigated areas, there are increasing concerns of resource degradation, stagnating productivity in the Rice-Wheat cropping system in the last two decades. In response to these concerns efforts over the past decades have led to development and promotion of alternatives to conventional agriculture. Zero-tillage for sowing of wheat is finding rapid acceptance together with alternate land management practices e.g. bed planting of wheat, laser leveling etc. In this respect thus the need is:

- The technologies need to be refined to suit specific situation/cropping system, particularly important will be to adapt zero-tillage/ crop residue in a cropping system/alternate cropping perspective

- Important will be to understand the implications of new technologies over a period of time. What effect this will have on resource use and quality; disease/ pests/ecological scenarios, long term changes in soil properties and their management implications.

- Most important will be to promote institutional changes which are conducive to achieve need based participation and multidisciplinary approaches to problem solving.

- Partnerships with private-public partners and a shift from few commodities base production paradigm to broader goals related to livelihoods which will ask for a greater role of social scientist to play to understand and include policy perspectives.

Conservation agriculture must therefore, emerge as a major R & D thrust for both irrigated and rainfed ecologies. In many rainfed areas improvement in resource base quality is a prerequisite for enhancing production. There is sufficient evidence to show that mulch based technologies in conjunction with zero tillage can led to improved capacity of soils to store rainfall, support crop and reduce erosion. There is a need is to identify situations where there are better chances to make impact and a need for integrating conservation agriculture with agro forestry situations. From the above assessment on conservation agriculture it is very clear that contrary to global experience, in India significant advances in conservation agriculture have been mostly in the irrigated well endowed systems. However, rainfed areas offer a wide scope for alternative to conventional agriculture as is evident from the global experience. Here, it will be important to learn from the experiences globally and work collaboratively. It is important to enhance the human resource development which will be “the critical” prerequisite in taking up some of these emerging areas of long term natural resources concern as a way for transition to achieve sustainable agriculture.

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