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Sustainable Management of Natural Resources for Food Security and Environmental Quality: Case Studies from India – A Review

S.P. Palaniappan, A. Chandrasekaran, D.S. Kang, Kuldeep Singh, R.P. Rajput, D.L. Kauraw, M. Velayutham, and R. Lal

Abstract The best management practices of soil conservation, water management (rainwater and groundwater), and soil fertility enhancement were tested and demonstrated in farmers' fields, in red soils (Alfisols), black soils (Vertisols), and alluvial soils (Entisols and Inceptisols) of India, under a range of crops and cropping systems. The project involved a community-based interactive participatory operational research model, with an intrinsic value of large-scale social and extension domain for adoption of sustainable agricultural practices.

In the dry land soils of South India disc ploughing to 30-cm depth during summer and contour bunding, and tied ridges with mulching were conservation-effective measures. Under the bimodal rainfall pattern in the region, intercropping of pigeon pea with pulses and use of compost and green manuring enhanced crop yields. Drip irrigation and arid horticulture were also successful in this region.

On-farm experiments conducted on alluvial soils of Punjab with diverse crop rotations of different water requirements showed that at Nawashahr the average yield of wheat was similar in the rice-wheat system (RWS) (4.0 Mg/ha) and maize-wheat system (MWS) (4.3 Mg/ha). Substituting maize for rice in the monsoon season is preferred because of savings in water. In Faridkot district, the economic returns were higher for the cotton-wheat system (CWS) which optimizes the use of groundwater resource better than the RWS.

Efficient on-farm water management using fertigation technology, agroforestry and fish culture, and intercropping with poplar were useful cyclic interventions in the land use and management strategy for sustainable agriculture in the intensively cultivated alluvial soils of Punjab.

For sustainable management of Vertisols of central India, yield of soybean increased by about 100% with raised bed and furrow system and by 55% in broad bed and furrow system compared with the flat bed system. Adoption of integrated nutrient management (INM) based on soil testing increased the yield of soybean

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(*Glycine max*) and wheat by 71% over farmers' practice at Narsinghpur compared with about 100% in the case of soybean and 187% in the case of wheat at Hoshangabad. Intercropping of soybean with pigeon pea (*Cajanus cajan*) in 4:2 ratio produced higher net return (Rs. 27,620/ha) and benefit:cost ratio (3.3:1) over either of the monocropping system. Aqua-agriculture system was a better alternative to traditional monocropping (Haveli system) in the monsoon season. Aquaculture in the ponded water in the bunded field during monsoon season and growing of wheat or chickpea in the winter season proved successful, and is being adopted in the region.

Keywords Participatory research · Land and water management · Red, black and alluvial soils of India · Sustainable agriculture · Environmental quality

1 Introduction

Of India's total geographical area, around 43% (142 Mha) is under agricultural land use. Monsoon-dependent agriculture is practiced on 58% of the arable land. The impressive and historic increase in foodgrain production since mid-1960s through the Green Revolution is attributed to three factors: spread of high-yielding crop varieties, expansion of irrigation by using surface and underground water resource, and increase in use of fertilizers and other agrochemicals.

The principal challenges on the food front that India faces at the onset of the twenty-first century are:

- Food insecurity: To meet the demand of the increasing population, India's food-grain production must go up to about 325 million tons (Mt) by 2025. To achieve this target, production has to increase at the rate of 7 Mt yr⁻¹ over the next 20 years, without much increase in irrigated cropland.
- Soil degradation: Land area affected by different processes of soil degradation is estimated at 81% of the agricultural land area. This includes water erosion, wind erosion, sand dune encroachment, riverines, ravines and gullies, poor drainage, and excessive salts. Urban sprawl is another factor encroaching upon arable land. Demographic pressure, soil degradation, urbanization, and conversion into non-agricultural land use all contribute to the rapid decline of per capita arable land area.
- Environmental pollution: Excessive and inappropriate use of chemicals and irrigation, removal of crop residues, and simplification of cropping systems have caused pollution of groundwater, eutrophication of surface water, contamination of soil, and deterioration of air quality. In many regions both surface water and groundwater are highly polluted. Agricultural practices such as biomass burning and inefficient use of chemicals and fertilizers emit greenhouse gases (GHGs) that contribute to global warming.

- Social and political stability: There is a strong relationship between food security, employment opportunities, gender/social equity, and social/political stability. Being an agrarian economy, it is important to strengthen agriculture growth which is a vital sector for peace and political stability.

Addressing these complex and interacting, biophysical and socio-economic/political factors underpinning food security and environmental quality requires (i) adopting an innovative approach and strategy for sustainable agriculture by assessing soil quality dynamics under changing farming/cropping systems based on intensive off-farm inputs (ii) involving farmers and land managers in the decision-making process, and (iii) developing a mechanism of exchange of information between scientists and farmers/land managers on the one hand and policy makers and industry stakeholders on the other.

2 Project Implementation

The project on "Sustainable Management of Natural Resources for Food Security and Environmental Quality" was initiated by the M.S. Swaminathan Research Foundation (MSSRF) in technical collaboration with The Ohio State University (OSU), Columbus, Ohio, USA, with financial support from Sir Dorabji Tata Trust. The on-farm study was conducted in three major agro-ecoregions and soils of India: the red soils of Pudukkottai and Dindigul districts in Tamil Nadu state of southern India, the black soils of Narsinghpur and Hoshangabad districts of Madhya Pradesh (MP) in Central India, and the alluvial soils of Nawashahr and Faridkot districts in Punjab in northwestern India. The methodology adopted consisted of participatory rural appraisals, transfer of the best management practices (BMPs) in soil and water management and crop husbandry to the farmers' fields, training programs for farmers on these practices, and promotion of micro-enterprises for enhancing livelihood opportunities. Organization of Farmers' Days and interaction with the local extension system helped in the dissemination of these results to other farmers in the villages.

The specific objectives of the project were to

1. test, validate, and extend adoption of BMPs to alleviate soil-related constraints through participatory research approach,
2. develop and introduce management practices for efficient utilization of soil, water, and organic resources to enhance and sustain productivity,
3. diversify production system by introducing legumes/pulses, vegetables, livestock, agroforestry, and aquaculture through on-farm demonstration and validation, and
4. restore degraded soils, enhance water recharge, and improve soil organic carbon (SOC) concentration.

The farmer-participatory on-farm research on the validation and adoption of BMPs in three contrasting agro-ecosystems and soils (Fig. 1) is presented below:

Location of the Project Sites

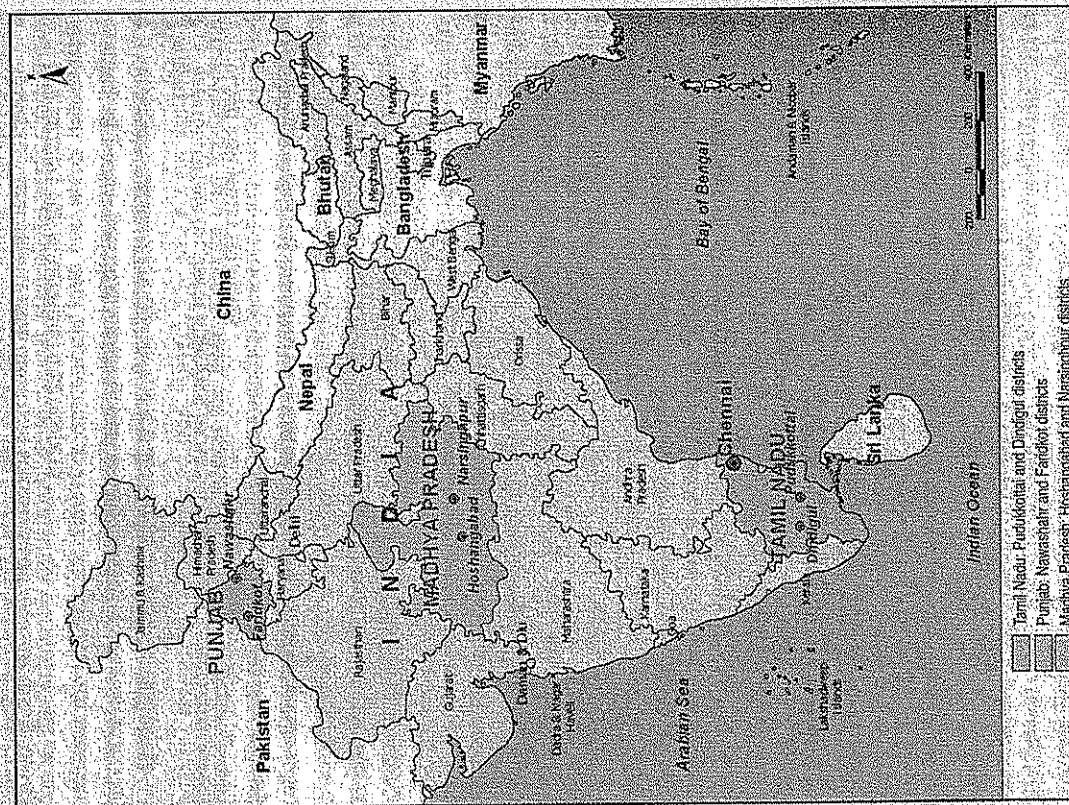


Fig. 1 Map of India

3 Alfisols in Semi-Arid Regions of South India

Alfisols of southern India have numerous soil-related constraints to adopting intensive cropping and enhancing crop yields. Effectiveness of highly variable and erratic monsoons is extremely low because of high intensity that generates a large volume of surface runoff, and high temperatures that cause severe losses by evaporation. Consequently, crops suffer from frequent and severe drought stress during critical growth stages. Adverse impacts of drought stress are exacerbated by the severe problem of soil degradation. Alfisols have inherently low soil fertility characterized by low nutrient reserves (e.g., N, P, K, Ca, Mg, Zn, Cu), low soil organic matter (SOM) content, low available water capacity (AWC), and consequently the low microbial biomass C. With predominantly coarse texture and scanty vegetation cover, crops suffer from supra-optimal soil temperatures exceeding 50°C in the top 0–5 cm layer. Adverse impacts of high soil temperatures and recurring drought stress are accentuated by the root-restrictive ground layer at 30–40 cm depth. Thus, alleviating these soil-related constraints by improving soil quality, conserving water in the root zone, moderating soil temperature, improving soil fertility, and enhancing SOM content are essential to increasing agronomic production. Agronomic benefits of improving soil quality can be realized only through improvement of soil quality and diversification of cropping systems.

Based on the participatory rural appraisal approach (Pretty, 1994; Velayutham et al., 2002b) and interaction with the farmers, the on-farm work plan was developed for 5 years (2001–2005). Field demonstrations were established at Ariyamuthupatti Village in Kudumianmalai Panchayat in Pudukkottai district of Tamil Nadu. Population of the region is entirely dependent on agriculture. Predominant soils of the district comprise degraded, infertile, red soils (Alfisols – Vayalagam series) in a semi-arid climate. The district is located between 8° 30' to 10° 40' N latitude and 78° 24' to 79° 40' E longitude in East Central Tamil Nadu, India, and falls in the 8.3 agro-eco sub-region of India (Velayutham et al., 1999; Natarajan et al., 1997). The district has a bimodal rainfall distribution with an average annual rainfall of 685 mm. About 40% of rainfall is received during southwest monsoon season (July–September), 44% during north-east monsoon (October–December), 7% during winter (January–February), and 9% in summer (March–June).

Farmland area of 5.1 ha leased from the community was chosen as the experimental-cum-demonstration farm. Initial soil analysis was done to establish baseline soil properties (Jackson, 1975). The data in Table 1 show a low level of plant-available nutrients of only 146 kg/ha of NPK and low cation exchange capacity (CEC) of 4.6 cmol (+)/kg⁻¹ of soil. The SOC concentration (0.26%) was below the critical level of 1.1% for soils of the tropics (Aune and Lal, 1998). The effective rooting depth is shallow, because the soil is underlain by a thick gravelly horizon. The surface soil has low AWC, and is prone to crusting, moderate-to-severe erosion, and acidification. The soils have a high P fixation capacity by iron and aluminum hydroxides.

Table 1 Nutrient status (0–20 cm) of the soil at Ariyamuthupatti village site just before sowing in 2001

Parameter	Value	Remarks
Available nitrogen (kg/ha)	52	Low
Available phosphorus (kg/ha)	14	Medium
Available potassium (kg/ha)	80	Low
Soil organic carbon (%)	0.26	Low
Extractable calcium (cmol kg ⁻¹ soil)	2.26	Low
Extractable magnesium (cmol kg ⁻¹ soil)	1.10	Low
Extractable sodium (cmol kg ⁻¹ soil)	0.34	Low
Cation exchange capacity (cmol kg ⁻¹ soil)	4.65	Low
Base saturation (%)	82.15	High
Exchangeable sodium (%)	7.3	Low
DTPA extractable zinc (ppm)	0.44	Low
DTPA extractable iron (ppm)	10.03	High
DTPA extractable copper (ppm)	0.62	Low
DTPA extractable manganese (ppm)	9.79	High

3.1 Water Management

At the start of the project, most of the rainfed soils in Ariyamuthupatti village had been uncultivated and left fallow for the past two decades. The farmers were reluctant to undertake the high risks of crop failure involved in cultivating these soils under dry farming conditions. Consequently, the village water pond (locally called tank) was uncared for several years and had been silted up by sedimentation because of uncontrolled and accelerated soil erosion. The pond was overgrown by weeds and shrubs (e.g., *Prosopis* spp.).

Seedbed preparation during summer was done by disc plowing to about 20 cm depth. Bunds were erected across the slope around the individual fields for diverting the excess rainwater into the channels. These channels, about 0.5-m deep with strengthened bunds installed on the contour, were connected to a main waterway. The latter with a gentle gradient, 0.75–1.0 m deep, drained into the pond. The latter was excavated to more than 1 m depth by farmers for storing the excess runoff water carried off from the fields through a network of channels and waterways. Periodic desilting and deepening of the pond was done by the village community throughout the study period. In addition to serving as a water reservoir, the tank also recharged the groundwater.

3.2 Climate and Crop Calendar

Being a rainfed agriculture area, importance was given to millets, pulses, and oilseed crops in crop planning. Improved varieties of pigeon pea (*Cajanus cajan* L.) tested involved those of varying growth duration. These included medium duration or MD

varieties (135 days) (APK1, CO5 and VBN1) and long duration or LD varieties (165–180) (VBN2, LRG30, ICPL87119). In general, LD varieties were better suited to this eco-region with a bimodal rainfall pattern than MD varieties. Furthermore, among LD varieties, the highest grain yield of 263 kg ha⁻¹ was obtained with the VBN2 variety. Four varieties of black gram (*Vigna mungo* L. Hepper) (VBN2, VBN3, CO6, T9) and three varieties of green gram (*Vigna radiata* L. R. Wilczek) (VBN2, CO6, K851), with growth duration range of 65–70 days, were also tested for their performance. Variety VBN2 of green gram and VBN3 of black gram performed relatively well in these soils and yielded 188 kg ha⁻¹ and 180 kg ha⁻¹, respectively. The prolonged dry spell in August coincided with the grain-filling stage and resulted in low yields.

3.3 Intercropping with Pigeon Pea

The best way to increase land equivalent ratio (LER) in rainfed monoculture is through intercropping that fits into the climate regime (Velayutham, 1999). The LD pigeon pea variety (VBN2) was tested for its productivity in an intercropping system (Fig. 2). Both groundnut (*Arachis hypogaea* L.) (TMV 3) and cowpea (*Vigna unguiculata* L.) (VBN1) were grown as intercrops. Pigeon pea was sown at a row-to-row spacing of 1.0 m. In between the rows of pigeon pea, three rows of cowpea and groundnut were sown at a spacing of 30 × 10 cm. It was found that intercropping of pigeon pea is climatically adaptable and economically advantageous for this region. Pigeon pea + groundnut was the best intercropping system in terms of net income (Rs. 4145/ha).

**Fig. 2** Red gram + green gram intercropping under mulching moisture conservation

3.4 Double Cropping

Double cropping or sequential cropping was evaluated by disc ploughing to 30-cm depth during the summer. In addition, water harvesting, using diversion channels and waterways, and supplemental irrigation were also used. Enriched press-mud was used to improve soil fertility. Compost was used in conjunction with foliar application of diammonium phosphate. Integrated pest management (IPM) was adopted against the pod borer damage in pigeon pea. The data in Table 2, about the yield of different cropping systems, show that agronomic productivity can be greatly enhanced in ecosystems with a bimodal rainfall pattern by growing two sequential crops under rainfed conditions. Pigeon pea + lablab (*Lablab purpureus* L.) and pigeon pea + groundnut intercropping systems produced the highest grain yields, even under conditions of uneven rainfall distribution. Among the double cropping systems, groundnut followed by cluster bean (*Cyamopsis tetragonoloba* L. Taubert) and radish (*Raphanus sativus* L.) produced the highest monetary returns. In comparison with the monoculture of pigeon pea, the minor millets varagu or Kodo millet (*Paspalum scrobiculatum* L.) and finger millet (*Eleusine coracana* L. Gaertn) also performed well, indicating the potential prospect of including these nutritious minor millets in cropping systems for advancing crop diversification, and food and nutrition security (Velayutham and Palaniappan, 2003).

Table 2 Agronomic yields and economic returns of a range of crops and cropping systems

First crop (July–Sept.)	Second crop (Oct.–Feb.)	Yield of first crop (kg ha ⁻¹)	Yield of second crop (kg ha ⁻¹)	Net income (Rs. ha ⁻¹)
Pigeon pea (LD) (pure crop)	Contd.	263	–	1,315
Pigeon pea (LD) + black gram	Red gram (contd.)	198	107	4,158
Pigeon pea (LD) + cowpea	Red gram (contd.)	109	123	1,780
Pigeon pea (LD) + groundnut	Red gram (contd.)	109	313	4,145
Pigeon pea (LD) + lablab	Red gram (contd.)	198	248	4,712
Pigeon pea (MD)	Red gram (contd.)	140	–	1,120
Black gram	Horse gram (contd.)	180	63	3,620
Green gram	–	188	–	3478
Cowpea	Bengal gram	27	64	1,457
Groundnut	Cluster bean & Radish	244	257	3,643
Sesame	Horse gram	121	165	1,638
Varagu (Kodo Millet)	Varagu (contd.)	634	–	2,219
Finger millet	–	594	–	2,673

Note: LD – Long duration; MD – Medium duration.

3.5 Summer Ploughing

Summer ploughing to ~30-cm depth enhanced soil water reserves during the southwest monsoon of 2004, primarily by breaking the crust and improving water infiltration rate. With intense rains received in July 2004, farmers included groundnut in the cropping system. Although there was a continuous dry spell for 52 days, the crop survived due to the moisture conserved through summer ploughing, resulting in an average yield of 1.67 Mg ha⁻¹ of pod. In some plots where summer ploughing was not done, the groundnut crop sown in July suffered from severe drought stress at critical stages of flowering, peg formation, and pod filling. The average groundnut yield was 600 kg pods ha⁻¹, or 36% of the yield obtained with summer ploughing. Vital et al. (1983) reported the beneficial effects of deep tillage on dryland crop production in red soils of India. The importance of summer ploughing is now widely accepted by the farmers of the district, and it forms an important component of the BMPs for dry farming in the region.

3.6 Composting

Farmers, in particular women, participated in the training program for the production of enriched compost using locally available crop residues of cotton (*Gossypium hirsutum* L.), pigeon pea, sugarcane (*Saccharum officinarum* L.), and raw press-mud obtained as a by-product from the nearby sugar refining factory. These materials were wetted and mixed with animal dung. Rock phosphate at 25 kg Mg⁻¹ of the material, zinc sulfate at 2.5 kg Mg⁻¹, *Trichoderma viride* at 5.0 kg Mg⁻¹, and phosphobacteria at 200 g Mg⁻¹ were added to the residues, mixed, and formed into heaps of 3 × 1.5 × 1 m dimensions. The moisture content of the heap was maintained at about 60% by sprinkling water periodically. The heap was turned over twice at 30 days and 45 days, and well-decomposed compost was ready for field application by 60 days after the start of the composting process.

The enriched compost was mixed with the appropriate inoculum of rhizobium or azospirillum (depending on the crop) and applied at the rate of 2.5 Mg ha⁻¹. Increase in crop yield by compost was 10% in pigeon pea, 58% in groundnut, 500% in onions (*Allium cepa* L.), and 12% in okra (*Abelmoschus esculentus* L. Moench). The strategy of using integrated nutrient management (INM) practices, including P-enriched compost, is important for these depleted and degraded Alfisols of southern India which have high phosphate fixation capacity. Farmers are now practicing the production of enriched compost as a component of BMPs for INM strategies.

3.7 Ridge-Furrow System and Tied Ridging

Ridges, furrows, and tied ridges were formed immediately after the first monsoon rains (Fig. 3). Four techniques of soil conservation and mulching and three of INM

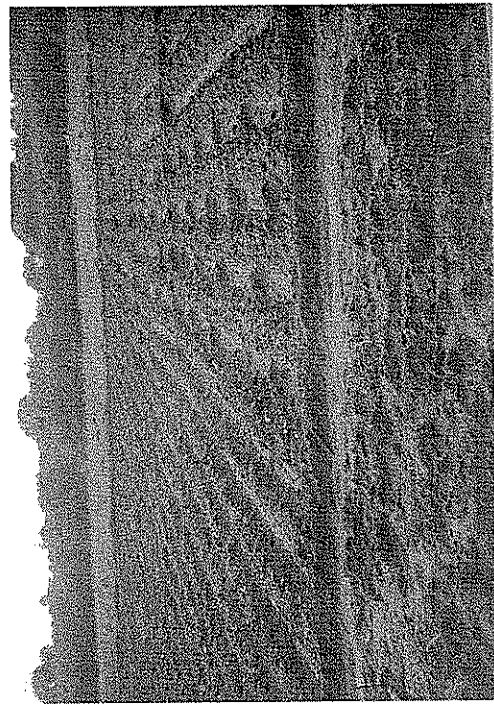


Fig. 3 Tied ridges

were laid out in a strip plot design with cowpea as a test crop in 2002 and 2003 seasons. Total amount of rainfall received during winter 2002 and 2003 crop period was 162 mm and 132 mm with distribution of 7 rainy days in both years. Crop residue mulch was applied at the rate of 2.5 Mg ha^{-1} about 15 days after sowing. The crop yield figures and the derived resource indices are given in Tables 7 and 8.

3.8 Productivity

Productivity was assessed by computing several productivity indices such as production efficiency (PE) and economic efficiency (EE) by the following formula (Singh et al., 2005):

$$\text{PE (\%)} = \left\{ \left(Y^{\text{IS}} - Y^{\text{TS}} \right) / Y^{\text{TS}} \right\} \times 100, \quad (1)$$

where Y^{IS} is the grain yield in intervention system and management and Y^{TS} is grain yield in traditional system and management.

$$\text{EE (\%)} = \left\{ \left(\text{NR}^{\text{IS}} - \text{NR}^{\text{TS}} \right) / \text{NR}^{\text{TS}} \right\} \times 100, \quad (2)$$

where, NR^{IS} is net returns in intervention system and management and NR^{TS} is net returns in traditional system and management. Energy efficiency was computed by evaluating the input and output of energy for each treatment (Dazhong and Pimentel, 1984). Rainfall use efficiency (RUE) was calculated by dividing the yield by total quantity of rainfall obtained during the cropping period. Solar radiation use efficiency (SRUE) for the cropping period was computed as per the procedure of Hayashi (1966) and expressed in g cal^{-1} .

$$\text{SRUE} = \frac{\text{Dry matter production } (\text{gm}^{-2}) \times 4000}{\text{Total incident energy } \times 0.45 (\text{Cal m}^{-2})}$$

The data in Table 3 show that tied ridges significantly improved cowpea performance through increasing soil water reserves in the root zone. In addition, mulching with groundnut crop residues reduced soil evaporation and increased crop yield. Among the INM treatments, application of enriched compost produced the highest yield. During the second year, tied ridges replaced the compartmental bunding treatment and ordinary compost application was replaced by application of 50% of inorganic fertilizer and 50% of enriched compost. Significantly more grain yield of cowpea was obtained under ridges and furrows with mulching (716 kg ha^{-1}) and tied ridges with mulching (297 kg ha^{-1}), during 2002 and 2003, respectively, over farmers' practice. Ridges and furrows with mulching had higher PE (25.11%), EE (13.2), RUE ($4.4 \text{ kg ha}^{-1} \text{ mm}^{-1}$), and SRUE (1.61 g cal^{-1}) during 2002 than other treatments. Tied ridges with mulching was superior to farmers' practice and ridges and furrows with mulching in PE (75.25%), EE (7.7), RUE ($2.3 \text{ kg ha}^{-1} \text{ mm}^{-1}$), and SRUE (0.74 g cal^{-1}) during 2003. Among nutrient management practices, application of enriched compost during 2002 and integration of 50% inorganic fertilizers and 50% enriched compost during 2003 produced significantly higher grain yield (731 kg ha^{-1} and 285 kg ha^{-1} , respectively) and at higher resource use efficiencies. Application of enriched compost improved PE (30.46% and 68.07%), EE (12.5 and 6.7), RUE ($4.5 \text{ kg ha}^{-1} \text{ mm}^{-1}$ and $2.0 \text{ kg ha}^{-1} \text{ mm}^{-1}$), and SRUE (1.67 g cal^{-1} and 0.69 g cal^{-1}) during 2002 and 2003, respectively, than inorganic fertilizers application and farmers' practice of no nutrient application. The advantage of tied ridges over farmer's practice on producing higher yield, even during seasons of sub-normal rainfall (2003), is significant (Ramesh and Devasenapathy, 2005, 2007a). Field observations during the cropping seasons showed (Ramesh and Devasenapathy, 2007a, b) that root growth (length, volume, and dry weight), and nodulation characteristics (numbers and dry weight) increased by these practices of soil moisture conservation (e.g., ridges and furrows, and tied ridges with mulching).

Similar results were obtained with pigeon pea crop experiment (Table 4). The highest yield of pigeon pea was obtained with tied ridges and mulching, among soil conservation treatments, and with application of enriched compost among the INM treatments. Soil moisture content (0–30 cm depth) was the highest throughout the growing season under tied ridges with mulching. Improved grain yield (476 kg ha^{-1}), PE ($8.9 \text{ kg ha cm}^{-1}$), and EE (15.63) were obtained with tied ridges with mulching. In soil management treatments, application of enriched compost significantly influenced grain yield (471 kg ha^{-1}) and nutrient uptake. The highest net returns of Rs. 5,731/ha from pigeon pea + green gram intercropping was obtained with the BMPs comprising of tied ridges and mulching. In accordance with the increase in agronomic yields, improvements in the post-harvest available soil NPK and SOC concentration were also observed with mulching in ridges and furrows and tied-ridges treatments (Ramesh and Devasenapathy, 2007b). Selvaraju et al. (1999) reported that tied ridging and application of manures in combination with N and P fertilizer improved soil water storage and yield of crops compared to sowing on the flat bed in rainfed Alfisols and related soils of the semi-arid tropics.

Table 4 Effect of land and nutrient management on pigeon pea yield and efficiency indices (2003)

Treatments	Grain productivity (kg ha ⁻¹)	Water productivity (kg ha ⁻¹ cm ⁻¹)	Energy efficiency ^c
Moisture (M)			
Farmers' practice	292.3	5.5	11.38
Ridges & furrows	353.6	6.6	12.23
(R&F)			
Tied ridges (TR)	393.7	7.4	13.45
R&F + mulching	454.5	8.5	15.18
TR + mulching	475.4	8.9	15.63
CD ($P=0.05$)	42.6		
Nutrient (N)			
Farmers' practice	271.2	5.1	14.0
Rec. NPK	391.2	7.4	12.5
50% NPK + 50% enriched compost	442.0	8.3	13.6
Enriched compost	471.2	8.9	14.2
CD ($P=0.05$)	21.0		

3.9 Low-Cost Gravitational Drip Irrigation System

A ground-level zero-energy drip irrigation system was installed in a farmer's field at Ariyamuthupatti and Kannivadi sites. The system involved installation of a PVC tank of 800 l capacity at an elevation of about 1 m. The tank was connected with a drip irrigation system. Drip line was laid in alternate rows of the crop, with 1 lph dripper spaced at 30 cm. The tank was filled from the nearby borewell once a day and tomatoes were transplanted during the dry season. Yield of fresh tomatoes of 23.2 Mg ha⁻¹ was obtained with 73.8% saving in water.

At Kannivadi site, the plots receiving drip irrigation yielded 15.2 Mg green chillies ha⁻¹, (*Capsicum annuum* L.) compared with the production of 9.4 Mg ha⁻¹ for plots with surface irrigation, an increase of 61%. The green chillies from the drip irrigation plots were larger, longer, and shinier than those from surface-irrigated treatments, and fetched a higher price in the market.

3.10 Arid Horticulture

Adopting rainfed horticulture is an important strategy for providing another income stream for farmers. In cooperation with the state-funded wasteland development project, seedlings of amla (*Phyllanthus emblica* L.), sapota (*Manilkara zapota* L.), and mango (*Mangifera indica* L.) were planted on 35 acres (14 ha) of uncultivated wasteland in the village. The farmers were advised to use pitcher pot irrigation and mulching with coconut husk and crop residues around the saplings for initial establishment and better growth of the seedlings during the summer period. This has been a successful undertaking, and a popular practice with the community.

Table 3 Effect of in situ rainwater harvesting on sustainable indicators of rainfed cowpea

Moisture conservation	Total biomass (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Total factor productivity	Production efficiency (%)	Energy productivity (kg MJ ⁻¹)	Energy efficiency
Winter, 2002						
Farmers' practice	2652.5 ^b	572.2 ^c	0.127	0.134	0.78	12.60
Ridges & furrows	2897.8 ^{ab}	662.8 ^{ab}				12.75
(R&F)						
Compartmental	2775.5 ^b	627.8 ^b	0.132	0.132	0.78	12.78
bunding (CB)	3008.8 ^a	715.9 ^a	0.143	0.143	0.81	13.20
R&F + mulching	2917.3 ^a	688.9 ^b			0.81	13.18
CB + mulching						
Winter, 2003						
Farmers' practice	956.3 ^c	169.7 ^c	0.066	0.066	0.37	5.96
Ridges & furrows	1117.0 ^b	208.5 ^b	0.072	0.072	0.40	6.53
(R&F)						
Tied ridge (TR)	1151.8 ^b	223.2 ^b	0.072	0.072	0.40	6.58
R&F + mulching	1345.2 ^a	279.0 ^a	0.088	0.088	0.46	7.48
TR + mulching	1406.6 ^a	297.4 ^a	0.089	0.089	0.47	7.70

Means within column followed by the same letter are not significantly different (L.S.D at $P=0.05$).

a,b,c Statistical difference among treatment means.

3.11 Soil Health Card

A soil testing campaign was organized in the project area with the assistance of soil testing laboratory, Kudumiammalai. The services of the mobile soil testing laboratory were also availed. Based on the soil test analysis of individual farms, "soil health cards" were printed and distributed to the farmers. Specific training sessions were organized for the method of soil sample collection, soil test interpretation, and the use of soil health card. Participating farmers appreciated the usefulness of these cards for periodic monitoring of soil health with the adoption of BMPs and recommended cropping systems.

3.12 Social Mobilization and Income-Generating Activities

Self-help groups were formed in order to create other livelihood opportunities and to generate off-season and off-farm income. The women self-help group formed comprised of Mangayi Amman Self Help Group, with 16 founding members, and Akilandeswari Self Help Group, with 12 founding members. Members were invited to the MSSRF centers at Kannivadi and Pondicherry to observe the functioning of the self-help groups in these centers and to interact with them in starting micro-finance-assisted micro-enterprise. The self-help group members mastered the technique of producing *Trichogramma* parasitoid production and supplied the cards to sugarcane cultivators, through a buy-back arrangement with the EID Parry Sugar Factory, located at Aranthangi, 30 km from project site. This arrangement was extremely effective in the biological control of sugarcane internode borer pest. This micro-enterprise and preparation of enriched compost has considerably improved the employment and income-generating capacity of the participating women.

4 Semi-Arid Black Soils (Vertisols) of Central India

Vertisols (black soils) occupy 7% of the arable lands in the semi-arid tropical region, and cover large areas under dry farming in Central and South India. Vertisols are derived from base-rich rocks (basalt) or the related colluvium or alluvium parent materials. These soils have a high clay content, and vary in depth (15–200 cm), clay content (30–70%), and cracking patterns, and are also highly prone to sheet erosion. Surface runoff varies from 10% to 40%, and increases with increase in rainfall. Heavy texture and waterlogging make it difficult for early and rapid seedbed preparation. Important soil groups in the region are Chromusterts and Pellusterts (Murthy et al., 1981; Swindale, 1982; Venkateswarlu, 1987).

In Central India, Vertisols have a large potential of increasing agricultural production provided appropriate technologies for conservation and management of natural resources, particularly soil and rainwater management, are widely implemented. Upland crops grown on these soils in high rainfall areas (>1,000 mm),

mainly soybean (*Glycine max*) and maize (*Zea mays*), are prone to temporary water-logging and anaerobiosis.

In India about 18 Mha of Vertisols (12 Mha in MP) are left fallow during the rainy/monsoon season. Therefore, these soils are cropped only during the post-rainy season on profile-stored soil moisture. The rainy season fallowing, locally called as "Haveli system" of cultivation, leaves the land unutilized and prone to severe erosion and runoff. The low water infiltration rate ($3\text{--}5\text{ mm h}^{-1}$) is attributed to high clay content (>40%) containing predominantly expanding-type clay minerals. Through adoption of BMPs, there is a vast scope to improve utilization of soil and water resources in the region for intensification of these inherently fertile soils. A community-based field operational research project was implemented with the specific objectives to (1) promote adoption of BMPs for rainfed and irrigated agriculture in Central India through demonstration of soil and water conservation measures and improved agronomic practices, (2) demonstrate the usefulness of INM practices, and (3) provide training opportunities to researchers, extension workers, and farming communities.

4.1 Ecoregional Characteristics of the Sites

On-farm demonstrations were established on two representative series of Vertisols in Narsinghpur and Hoshangabad districts of MP state (MSSRF, 2006). These two districts come under 10.1 (Malwa Plateau, Vindhyan and Narmada Valley) hot, dry sub-humid eco-sub region (Velayutham et al., 1999). The sub-region is characterized by sub-humid climate with dry summers, mild winters, and ustic soil moisture regime. Temperature ranges from 31°C to 40°C in summer and $9\text{--}19^{\circ}\text{C}$ in winter. Annual rainfall ranges from 1,000 mm to 1,500 mm and length of the growing period from 150 days to 180 days. Soils of the demonstration sites were shallow to moderately deep, moderately well drained, slowly permeable, clayey Vertic Ustochrepts and Ustorthents in the gently sloping uplands, and very deep, clayey Chromusterts in the nearly level uplands (Tamgadge et al., 1999).

The water table (WT) was below 10 m at Narsinghpur, and at 5–10 m depth at the Hoshangabad sites. Groundwater was the source of irrigation at the Narsinghpur site, whereas canal irrigation from Tawa Command was used at the Hoshangabad site. The WT's declining at the Narsinghpur site at the rate of $15\text{--}20\text{ cm yr}^{-1}$, whereas the WT in "B" zone of Tawa Command at Hoshangabad is increasing at the rate of 20 cm yr^{-1} . Both areas need judicious use of available water resources for sustaining high agricultural productivity. The characteristics of the soil at the two sites are given in Tables 12 and 13. Total SOC pool to 120 cm depth was 89.6 Mg ha^{-1} for the Narsinghpur site and 74.2 Mg ha^{-1} for the Hoshangabad site. The clay content ranged from 42.1% to 46.1% for the Narsinghpur site and 43.5% to 50.0% for the Hoshangabad site. Both soils had a high water holding capacity at 33 KPa suction or field moisture capacity (30–40% by weight). Total AWC to 120 cm depth (computed on volumetric basis for the specific depths) was 27.5 cm for the Narsinghpur site and 25.8 cm for the Hoshangabad site.

These soils are characterized by typical morphological features called "slicken sides", which are caused by the presence of swell-shrink minerals like smectites. Vertisols are difficult to plough during the rainy season, and need proper land configuration and soil conservation measures for effective irrigation and crop production.

Field demonstrations were established on ten farms in three villages (viz., Dangidhana, Bagpodi, and Murlipodi) in Narsinghpur district, and expanded to 20 farms later. Similarly ten farmers' fields were selected in three villages (viz., Mongwari, Bhairakhedi, Dolariya) in Hoshangabad district, and expanded to 40 farms later during the second and third years.

4.2 Land Forming For Soil and Water Conservation

The raised/sunken bed system (RSBS) of land treatment was established on farmer's fields. The system consists of an array of raised and sunken beds of 8-m width, with elevation difference of 30 cm. The system is created by mechanically moving soil from demarcated 6-m-wide strips, designated as sunken beds. Beds thus created are tied across with small earthen bunds of about 10 cm height at 20 m interval to ensure uniform spread of runoff in sunken beds. The runoff from raised beds is diverted and captured in the adjacent sunken beds. The RSBS (Fig. 8) facilitates drainage for growing upland crops, encourages in situ rainwater conservation, and minimizes soil erosion and nutrient losses.

During the winter season, grain yields of wheat sown in sunken bed and chickpea in raised bed were compared with those from the flat bed system (FBS) of cultivation. During the summer monsoon season, soybean (*Glycine max* L.) was sown in the raised bed and rice in the sunken bed. The results given in Table 14 indicate the beneficial effects of RSBS over the FBS on the yield of wheat and chickpea. The RSBS, once formed, stabilizes over time (cropping cycles) and increases the benefit:cost (B:C) ratio over the FBS.

Two land configuration treatments, namely, ridge-furrow system (RFS) and broad bed and furrow system (BBFS), were compared with the FBS of planting soybean. The ridges were formed 15–20 cm high on 0.5% grade. The BBFS involved erection of 150-cm wide and 15-cm high raised beds on 0.4% grade. The beds were separated by 50 cm wide furrows that drained into grassed waterways. Increase in soybean yield was about 100% with RFS and 55% with BBFS compared with the farmers' practice. Selvaraju et al. (1999) reported that BBF and compartmental bunding land configuration could be adopted on Vertisols for better water conservation and crop productivity.

4.3 Integrated Plant Nutrient Management Practices (INMP)

Eight trials were conducted at the Narsinghpur site to demonstrate the effectiveness of integrated nutrient management practices (INMP) for wheat and chickpea (*Cicer arietinum*). The results given in Table 15 indicate that INMP treatment produced

the maximum yield in comparison to the general recommended fertilizer alone. With INMP treatment, an additional income of Rs. 6,978 per ha and Rs. 1,1976 per ha was obtained for wheat and chickpea, respectively, over the farmers' practice. Similar results were obtained with soybean trials established on 15 locations at the Narsinghpur site. The highest soybean yield (2.58 Mg ha^{-1}) was obtained under INMP + 4 Mg ha^{-1} application of farmyard manure (FYM), which generated an additional income of Rs. 6,847 ha^{-1} compared to the farmers' practice.

4.4 Hoshangabad Site

Ten demonstration trials were conducted at the Hoshangabad site to assess the BMPs for wheat var. DL-788-2 in comparison to farmers' practice. The high yield (4.0 Mg ha^{-1}) was obtained with adoptions of BMPs as compared to 1.4 Mg ha^{-1} obtained under farmers' practice. Similar results were obtained with soybean, with the doubling of yield by the adoption of INMP.

4.5 Intercropping of Soybean

One of the improved agronomic practices in soybean cultivation is intercropping of soybean with pigeon pea. The results of demonstrations conducted in a farmer's field (Table 16) indicate that this system is compatible in 4:2 ratio (four lines of soybean and two lines of pigeon pea) and produced higher net return (Rs. 27,620 ha^{-1}) and B:C ratio (3.3 : 1) over either of the two monocultures.

4.6 Water Management in Rice

One of the improved agronomic practices in rice cultivation is the water management or the frequency of flooding. In general, farmers continuously flood rice fields for the entire growing period. Through irrigation at critical stages of the crop rather than continuous flooding, there is scope for water saving without causing yield reduction. Thus, a demonstration experiment on the effect of irrigation management on rice was established. The data showed that with three irrigations at critical stages, rice yields were (3.8 Mg ha^{-1}) equivalent to that of the continuous flooding (3.5 Mg ha^{-1}). This demonstration has created awareness among farmers in the region about the benefits of water conservation technology for growing rice.

4.7 Aqua-Agriculture

The "Haveli system" of cultivation of vertisols in Central India entails ponding the rainwater in bunded fields during the rainy season (to minimize losses by runoff and

erosion) and growing wheat or chickpea in the post-rainy season on stored profile moisture. The available rainwater is not effectively utilized, and the land is left fallow. Raising fish during the rainy season in these fields and growing crops in the post-rainy season can augment farmers' income and enhance employment throughout the year.

A 2-ha field was selected for demonstration and three species of fish (i.e., Mrigal, Rohu, and Katla) were introduced, according to the standard management practices. Wheat and chickpea were sown in the same field after fish harvest in October. The results of this demonstration (Table 17) showed that fish-wheat or chickpea rotation in the field increased the net returns considerably more than following during the rainy season and cropping only during the winter. The data highlights the feasibility and economic advantage of adopting aqua-agriculture in the vast Vertisol region of MP. The demonstration trials of this kind conducted in farmers' fields provided excellent loci for dissemination of this important technology.

4.8 Optimizing Nutrient and Water Management in Soybean–Wheat System

Two field experiments to maximize the interactive effect of water and nutrient resources were conducted on soybean-wheat cropping systems under varying fertility and irrigation levels. Three moisture regimes (i.e., irrigation at seedling/transplanting (I_0), moderate moisture regime (I_1) and optimum moisture regime (I_2)) in combination with nine nutrient sources (S_1 – S_9) were evaluated. The irrigation schedule for the three treatments for the two crops was as follows:

Irrigation	I_0	I_1	I_2
Soybean (Monsoon)	No irrigation	Irrigation at 60 DAS	Irrigation as per need
Wheat (Winter)	Come-up irrigation + 21 DAS	Irrigation at 21 and 45 DAS	Irrigation at 21, 45, 75, and 90 DAS

DAS = Days after sowing.

The nine nutrient levels were: 100% NPKS optimum dose as per soil test (S_1); 75% of optimal dose + 5 Mg ha⁻¹ of FYM (S_2); 50% of optimal dose + 5 Mg FYM ha⁻¹ (S_3); S_2 + rhizobium/Azotobacter 1.5 kg ha⁻¹ (S_4); S_2 + phosphate solubilizing bacteria (PSB) @ 1.5 kg ha⁻¹ (S_5); S_2 + PSB + rhizobium (S_6); S_6 + Zn @ 10 kg zinc sulfate ha⁻¹ (S_7); S_6 + Mo as ammonium molybdate @ 0.5 kg ha⁻¹ (S_8), and S_6 + Zn + Mo (S_9).

The highest yields of soybean (2.4 Mg ha⁻¹) and wheat (4.4 Mg ha⁻¹) were obtained under I_2 moisture regime. In the case of nutrient sources, grain yield was significantly higher in S_9 than other treatments. The treatment combination $I_2 S_9$

(optimum moisture level and integrated nutrient sources) was the best for grain yield of both crops.

4.9 The “Seed Village” Model

The availability of good-quality seeds of high-yielding varieties (HYV) of crops is a major constraint among farmers' to realizing the full benefits of HYV technology. The use of harvested grains as seed, in successive seasons, reduces the seed vigor and crop yield. Mobilizing farmers in a village as “seed farmers” to multiply the breeder's seed and ensure seed replacement by all farmers in the village provides the best means of quality seed delivery system and the impact of seed replacement and assisted this process in the selected villages and the impact of seed replacement and the increase in average yield in the villages are given in Tables 18 and 19, respectively. In 3 years, the production and distribution of HYV of crops increased the average yield of soybean, wheat, and chickpea by 50%, 30–50%, and 50%, respectively. Such an approach is important to achieving self-sufficiency in quality seed production and distribution at the local level.

5 Alluvial Soils of the Indo-Gangetic Plains

The Indo-Gangetic fluvial Plains (IGP) of India extend from 21° 45' to 31° 0' N latitudes and 74° 15' to 91° 30' E longitudes, and include the states of Punjab, Haryana, Delhi, Uttarpradesh, Bihar, West Bengal, Himachal Pradesh, northern parts of Rajasthan, and Tripura. The IGP cover a total area of 43.7 Mha. Velayutham et al. (2002) have discussed the historical perspective and pedogenesis of the soils of the IGP.

Punjab state, situated in the western part of the IGP, comprises an area of 5 Mha and contributes annually to more than 60% of wheat (*Triticum aestivum*) and 45% of rice (*Oryza sativa*) to the national food reserves. The rice-wheat system (RWS), being highly profitable, has been adopted even in non-traditional areas. In Punjab from 1987 to 2007, the area under rice cultivation increased by more than ten times and under wheat by 2.5 times. The RWS in Punjab is irrigated, and is an intensive input-driven and a soil-exhaustive cropping system. Between 1960/1961 and 2001/2003, irrigated land area increased from 59% to 95%, cropping intensity from 118% to 186%, and food grain production from 3.2 Mt to 24.8 Mt (Statistical Abstracts, Govt. of Punjab).

Irrigation has led to excessive withdrawal of groundwater in most of Punjab. There is a decline in WT in the central districts and a rising trend in the southwestern districts of the state. Further, there is a declining trend in soil fertility and a rising trend in salinity and degradation of irrigation water quality leading to the fatigue of the RWS (Sinha et al., 1998). The problems of declining soil fertility are exacerbated by improper management of crop residues. Burning of the rice straw,

widely practiced in Punjab, leads to the loss of nutrients, environmental problems of air pollution, and health hazards.

5.1 Ecoregional Characteristics of the Demonstration Sites

The field demonstrations/experiments were conducted in farmers' fields in four locations (Barbha, Sajawalpur, Rakkaran Dhahan, and Baghauraan) in Nawashahr district, and four locations (Kothae Maur, Sadiq, Sandhwan, and Nathewala) in Faridkot district. The Farm Science Centre at Langroya in Nawashahr district and the Regional Agriculture Research Station and the Farm Science Centre at Faridkot provided the technical support. Specific objectives of the project were: (1) demonstration and adoption of techniques for efficient management of soil, water, and crop residues, (2) identification of cropping systems as viable alternatives to RWS which alleviate the pressure on groundwater resources, (3) assessment of agronomic productivity of diversified production systems, and (4) creation of training opportunities for researchers, extension staff, and farming communities.

Nawashahr district is situated in the hot, dry sub-humid climatic zone at 31° 32' N latitude and 75° 54' E longitude and forms part of northern flat plain with alluvium-derived soils. It is a part of the 9.1 agro-eco sub-region with growing length of 120–180 days (Velayutham et al., 1999). The mean winter and summer temperatures are 14.2°C and 34.4°C, respectively, with mean annual temperature of 23.5°C. The average annual rainfall is 850 mm. The soils are classified into three sub-groups, namely Typic Haplustalf, Udic Ustochrept, and fluventic Ustochrept (Sidhu et al., 1995). Soils are characterized by an alkaline pH, low EC, and low SOC concentration (Table 5). The RWS is the dominant cropping system in this district, 82% of the area is irrigated by tube wells, and the WT is falling rapidly (Fig. 4).

Faridkot district is situated in the semi-arid climatic zone at 30° 40' N latitude and 75° 45' E longitude and forms part of northern alluvial plain with sand dunes. It is a part of the 4.1 agro-eco sub-region, with growing season length of 90–150 days. The mean winter and summer temperatures are 13.9°C and 32.1°C, respectively, with a mean annual temperature of 24°C. The average annual rainfall in the district is 427 mm (Velayutham et al., 1999). The soils of the experimental site are very deep,

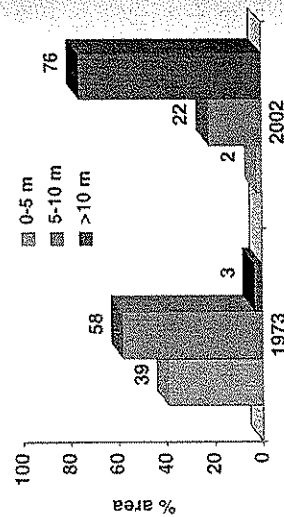


Fig. 4 Percent area under a range of water table depths (m) in Central zone of Punjab

Table 5 General properties of soils at two experimental sites in alluvial soils of Punjab

Soil characteristics	Langroya	Faridkot
Texture	Loam	Sandy loam
pH	8.0–8.7	8.5–9.4
E.C. (ds m ⁻¹)	0.2–0.3	0.2–0.4
Organic carbon (%)	0.4–0.6	0.2–0.6
Available P (Kg ha ⁻¹)	6.8–13.5	9.2–24.8
Available K (Kg ha ⁻¹)	202–397	405–562
CaCO ₃ (%)	0.35–1.0	0.7–1.2
Extractable calcium (µg g ⁻¹)	613–754	557–681
Extractable magnesium (µg g ⁻¹)	351–584	97–289
Extractable sodium (µg g ⁻¹)	18–70	41–162
DTPA-extractable Zn (µg g ⁻¹)	0.4–0.8	0.4–0.6
DTPA-extractable Fe (µg g ⁻¹)	3.1–9.8	2.0–5.2
DTPA-extractable Mn (µg g ⁻¹)	1.7–4.1	0.9–2.5
DTPA-extractable Cu (µg g ⁻¹)	0.5–1.4	0.3–1.0

well drained, and developed on reworked sand dunes. These soils are classified as Ustipsamments, have alkaline pH, and are calcareous. The major source of irrigation is the groundwater (84%). Both RWS and cotton (*Gossypium hirsutum*)-wheat system (CWS) are the dominant crop rotations in the district. Soil characteristics of the two locations, one in each district, are given in Table 5. The chemical properties, organic carbon, available soil nutrients, bulk density, and infiltration rate were determined as per the procedures given in "Methods of Soil Analysis" (SSSA, 2002).

5.2 Alternatives to Rice-Wheat Cropping System

Three cropping systems tested at Langroya site were RWS, maize (*Zea mays* L.)-wheat system (MWS), and maize-field mustard (*Brassica rapa* L.)-rapeseed (*Brassica napus* L.) system (MTRS). The initial soil analysis showed that the SOC concentration ranged from 0.46% to 0.60%, available P from low to medium, and available K from medium to high. Similarly, three cropping systems tested at Faridkot site were RWS, CWS, and cotton-chickpea (*Cicer arietinum*) system (CCS). The SOC concentration at these sites were much lower, (e.g., 0.21%–0.31%), available P from medium to high, and available K was relatively high.

All crops in diverse rotation systems were grown with the standard package of agronomic practices. The yields of crops in the different crop seasons show that the average yield of wheat (second crop) at Langroya was similar for the RWS (4,009 kg ha⁻¹) and the MWS (4,362 kg ha⁻¹). Similar wheat yield in both systems indicates that the lead time available for land preparation for sowing wheat, unless no-till (NT) is practiced, is more following maize than rice cultivation. The average yield of maize was also similar in MWS (4,455 kg ha⁻¹) and MTRS (4,470 kg ha⁻¹).

Comparative economics of diverse cropping systems was assessed for the participating farms. The highest returns were obtained with input of fertilizers followed

by that for irrigation. The RWS was the most economic system at Langroya, probably due to the minimum support price offered by the government for procurement of rice and wheat immediately after harvest. However, MWS and MTRS were also profitable cropping systems. Joginder Singh and Hossain (2003) reported the decelerating trend in TFP growth for rice in high-production RWS of North India. In view of the receding WT, rotations substituting maize for rice during the crop cycles in the monsoon season is a viable option that merits attention. At Faridkot, the economic returns from CWS were as good as those for RWS. However, cultivation of cotton is not economical due to heavy dependence on pesticides. In this regard, the use of B₁ cotton may be a viable option. The lowest economic returns were obtained from the rice-based system.

A corroborative sample survey was undertaken on selected farms in the project area. The data show that the benefit:cost ratio (BCR) was more favorable for wheat under the present price structure (Table 6). Average return was the highest for irrigation, followed by that for fertilizers.

Other indicators of economic assessment (e.g., GR, VE, ROVE) were higher for the RWS in Nawashahr district and for the CWS in Faridkot district compared with all other cropping systems. In Faridkot district, therefore, the adoption of CWS ensures an economic use of groundwater resource compared to the RWS. Thus, CWS has replaced RWS in most of the districts. The area under cotton in the operational villages (Sadiq and Kothae Maur) increased from 80 ha and 20 ha, respectively, in 2002 to 200 ha and 144 ha in 2004, respectively. Similarly, the area under cotton in the Faridkot district increased from 16,000 ha in 2002 to 30,000 ha in 2004.

Table 6 Comparative economics of alternate cropping systems in sample farms (Rs. ha⁻¹)

District	Rotation	GR	VE	ROVE	B:C ratio
Nawashahr	Rice-wheat	62,865	31,365	31,500	2.00
	Maize-wheat	45,005	24,093	20,912	1.87
Faridkot	Rice-wheat	64,590	32,765	31,822	1.97
	Cotton-wheat	63,200	30,858	32,342	2.05

GR – Gross returns; VE – Variable expenses; ROVE – Return over variable expenses; B:C Ratio – Benefit–cost ratio.

5.3 Residue Management in Rice–Wheat Cropping System

With the large-scale adoption of RWS in Punjab, the management of rice straw and seedbed preparation for timely sowing of wheat are principal agronomic challenges that must be addressed. Because of its low nutritional value as a fodder for livestock, rice straw is commonly burnt. Logistically, it is an easier option in the combine-harvested rice fields. However, burning of rice straw has adverse impact on soil quality, especially on SOC concentration and nutrient cycling. Rather than burning it, NT sowing of wheat through the mulch of rice straw can be agronomically viable



Fig. 5 Wheat sown under no tillage

and economically profitable (Fig. 5). Therefore, demonstrations on residue management were established at three locations in Langroya (Barbha, Sajawalpur, KVK farm) and at two locations (Sadiq and Kothae Maur) in the Faridkot sites.

Comparing the data on initial and final soil analyses (Table 7) show management-induced changes in SOC concentration even over a short period. The SOC concentration was affected by residue management after three crops at Nawashahr. It increased from an average initial level of 0.44% to 0.50% when both rice and wheat straw were burnt, 0.51% when rice straw was incorporated but wheat straw was removed, and 0.57% when both rice and wheat straw were incorporated. The increase in SOC concentration due to incorporation of both rice and wheat straw was statistically significant. Although a similar trend was observed at Faridkot location, the differences in SOC concentration were statistically not significant.

The effects of these residue management treatments on the yield of second crop of wheat (third crop in the rotation) are given in Table 8. The wheat yield at Langroya in plots where rice and wheat straw were burnt was somewhat more (5.1 Mg ha⁻¹) than that where the straw was incorporated (4.4–4.6 Mg ha⁻¹). Even with an increase of about 13%, the difference in yield is statistically not significant. However, incorporation of both straws at Faridkot sites was more beneficial than burning. In the latter case, the soils are light-textured (sandy loam) as compared to the loamy soil at the Langroya site. Thus, yield response to residue management seemingly depends on soil texture and other properties (e.g., moisture retention).

Table 7 Soil organic carbon as affected by residue management (winter 2002–2003)

Treatment	SOC (%)				Faridkot	
	Nawashahr		KVK farm		Mean	Sadiq
Initial	Barbha	0.51	Sajawalpur	0.48	0.44 ^b	0.33
Burning of both rice and wheat straw	Barbha	0.53*		0.47		0.32
		0.49**		0.47		0.28
		0.60***		0.51	0.50 ^{ab}	0.27
Incorporation of rice straw in wheat	Barbha	0.54*		0.54		–
		0.54**		0.54		–
		0.58***		0.51	0.51 ^{ab}	–
Incorporation of rice and wheat straw + GM	Barbha	0.52*		0.51		0.41
		0.47**		0.51		0.36
		0.61***		0.57	0.57 ^a	0.42

* After winter 2001–2002, ** After monsoon 2002, *** After winter 2002–2003 GM – green manure
Means within column followed by the same letter are not significantly different (L.S.D. at P 10%).
a,b,c Statistical difference among treatment means.

Table 8 Grain yield of wheat (winter 2002–2003) at different sites in residue management experiments

Treatment	Grain Yield (Kg/ha)				Faridkot	
	Nawashahr		KVK farm		Sadiq	Kothae Maur
Burning of both rice and wheat straw	Barbha	5780	Sajawalpur	5243	4573	4787
Rice straw incorporation and wheat straw removed		5723		4328	3923	–
Incorporation of rice and wheat straw + GM		5165		4348	3790	5512*

* Without green manure

Experiments conducted in farmers' fields in both districts also indicated similar trends in crop yields. The data analyzed to assess comparative economics of residue incorporation in the RWS over 3 years showed that since the GR as Rs ha⁻¹ were the same in straw-burnt and straw-incorporated treatments, the improvements in soil quality that the straw incorporation brings about in the long-term may offset the apparent advantage of burning straw giving the higher BCR in the short-term. This is an important management issue brought about by the changing land use scenarios in all agro-ecoregions of the IGP (Velayutham, 1994; Abrol and Gupta, 1998; Velayutham et al., 2000).

5.4 Residue Management and Soil Organic Carbon Sequestration

The positive effects of incorporation of straw in Faridkot sites are also corroborated by the attendant improvements in soil physical properties (Table 9). There was a slight increase in SOC concentration in straw-incorporated plots. With straw incorporation, the SOC pool increased by 0.2 Mg ha⁻¹ in 0–15 cm depth for the Nawashahr site. In comparison, increase in SOC pool by straw incorporation was by 1.0 Mg ha⁻¹ for the Faridkot site (Table 9). Soil bulk density decreased and there was a perceptible increase in water infiltration rate in soils. These results demonstrate the positive effects of straw incorporation in light-textured soils on improving the soil quality (Lal, 1995).

Swarup et al. (2000) estimated that there was 59% depletion of OSC concentration of cultivated compared with that in undisturbed soils in the IGP during 1960–2000 period. Bhattacharya et al. (2007) modeled SOC pools and changes in the IGP, India, from 1990 to 2030, using output of the GEFSOC modeling system. The predicted average SOC pool change rate in agro-ecological sub-region 4.1, which includes Faridkot district, by rice-wheat-clover rotation is 0.076 Tg yr⁻¹, 0.025 Tg yr⁻¹, and 0.157 Tg yr⁻¹ for 1990, 2000, and 2030, respectively. In contrast, for the RWS the corresponding values are –0.740 Tg, –0.636 Tg, and 0.260 Tg respectively. This trend shows the importance of reviving clover (*Trifolium alexandrinum*) in RWS to enhance SOC sequestration. Lal (2004) described the practices and their potential of SOC sequestration in soils of India.

Table 9 Effect of residue incorporation on soil organic carbon (%), SOC pool (Mg ha⁻¹), bulk density (Mg m⁻³), and infiltration rate (mm/hr) – 2003–2004

Treatment	Nawashahr				Faridkot			
	SOC	BD	SOC Pool	IR	SOC	BD	SOC Pool	IR
Burning of rice and wheat straw	0.52	1.53	11.9	3.5	0.45	1.65	11.1	6.1
Rice straw incorporated & wheat straw removed	0.53	1.50	11.9	3.5	0.42	1.60	10.1	6.7
Rice & wheat straw + GM incorporated	0.57	1.42	12.1	3.1	0.51	1.58	12.1	7.6

SOC = Soil organic carbon

BD = Bulk density

IR = Infiltration rate

SOC pool (0–15 cm depth)

GM = Green manure.

5.5 More Income Per Drop of Water

In view of the rapidly receding WT, and the need for popularizing efficient on-farm water management, the project staff assisted Mr. S. Kuldeep Singh, a progressive farmer at Kotkapura, in Faridkot district, in installing and demonstrating a drip irrigation system and using fertilization for growing vegetables all through the year



Fig. 6 Drip irrigation in vegetables

in his farm (Fig. 6). The soil of the farm is sandy loam with pH of 8.6, E.C. of 0.2 ds m^{-1} , CaCO_3 of 1.7%, and SOC concentration of 0.39%. The available P status is low to medium ($15.3 \text{ kg P ha}^{-1}$) and that of available K is high (566 kg K ha^{-1}). Irrigation with nutrients (fertilization) was used at the drip discharge rate of 2.0 l hr^{-1} for only a few minutes per day. The yield of tomato (*Lycopersicon esculentum* L.) was 52.5 Mg ha^{-1} and that of bittergourd (*Momordica charantia* L.) was 8.75 Mg ha^{-1} . The quality of produce in both crops was better and fetched higher prices in the market. This farm is now a focal point for dissemination of the fertilization technology to the farming community in the region (MSSRF, 2006).

5.6 Agricultural Diversification

5.6.1 Agroforestry

Only 5.6% of the land area in Punjab is under forests, compared with >84% under cultivation. It is thus logical to popularize agroforestry systems. Poplar (*Populus deltoides*) is among the fast-growing winter trees that can grow well in association with field crops (Fig. 7). Being a deciduous tree, large amount of organic matter and nutrients can be recycled through leaf litter added to the soil.

Two demonstration sites were established to assess the feasibility of intercropping with poplar. Maize as monsoon crop and wheat, mung bean (*Vigna radiata* L.) as winter crops were intercropped with poplar. There was no deleterious shade effect of poplar trees on the yield of either of these crops (Table 10). The leaf samples of poplar trees were collected during the autumn and analyzed for nutrient contents.



Fig. 7 Turmeric and ginger as intercrops with poplar



Fig. 8 Raised bed/sunken bed system. Soybean-rice system

Table 10 Yield of intercrops in poplar (*Populus deltoides*)

Crop Rotation	Grain yield (Kg ha ⁻¹)	
	Baghauran, Langroya	Khara, Faridkot
Wheat/Maize	4463/1150	Wheat/Moong
Poplar + wheat/maize	—	—
Poplar + wheat/moong	—	4625/217

Nitrogen concentration ranged from 1.7% to 1.9%, P from 0.08% to 0.09%, K from 0.26% to 0.28%, S from 0.12% to 0.14% Ca from 2% to 2.5%, and Zn from 4.2 ppm to 4.7 ppm. Thus a large amount of nutrients are recycled. In addition, poplar generates another income stream, from the same unit area under the agroforestry system. It also leads to SOC sequestration in these calcareous sodic soils of the IGP when practiced as a cyclic agroforestry intervention (Gupta and Rao, 1994).

5.6.2 Aquaculture

Towards an attempt at diversification of agriculture in Punjab, a poorly drained agricultural field with impounded water was used for aquaculture. On-farm demonstrations in the farm of S. Gurcharan Singh were established on 0.4 ha (1 acre)-size pond at Nathawala Nawar in Faridkot district. The fish feed consisted of FYM 0.48 Mg, poultry manure 0.24 Mg, single superphosphate 15 kg, deoiled rice bran 8.8 kg, deoiled mustard cake (*Brassica juncea*) 8.8 kg, soya meal 6 kg, mineral mixture 240 g, and salt 80 g. Four species of fish were grown in the pond. Fish production (Table 11) proved successful in 3 years, and was an economically viable intervention in regions where water is available in adequate quantities. This is an important diversification to the traditional cropping system.

Table 11 Fish aquaculture on a 0.4 ha pond in Faridkot district
Farmer: S. Gurcharan Singh Village: Nathawala Nawar District: Faridkot

Species	Weight at maturity	Average yield (Mg ha ⁻¹) of four species		
		2002	2003	2004
<i>Catla catla</i> (Catla)	1.0 kg			
<i>Labeo rohita</i> (Rohu)	600–800 g			
<i>Cirrhina mrigala</i> (Mirgal)	700 g	2.34	2.75	2.49
<i>Cyprinus carpio</i> (Common carp)	600–800 g			

5.6.3 Sustainable Management of Vertisols

Vertisols are an important cropland soil in central India. These soils have a high clay content, low organic matter reserves, high water retention capacity, but low water infiltration rate (Tables 12, 13). On-farm experiments have been conducted at two locations in central India, Narsinghpur and Hashangabad in MP. Among soil-related constraints to production, lack of micro-nutrients and low available water capacity are major determinants of crop yield. Growing crops on raised-sunken beds had relatively less beneficial impact on crop yields (Table 14, 15) than the application of INMP. Agronomic productivity and profitability were more with soybean-pigeon pea intercropping than with monoculture (Table 16). Because of low infiltration rate and inundation during the monsoon season, raising fish during the rainy season followed by wheat-gram rotation is an economically viable and sustainable use of these soils (Table 17). Another income stream for the small-land holders of Vertisols is through multiplication of breeder seed (Table 18, 19).

Table 12 Properties of a Vertisol at Narsinghpur site, MP state, India

Soil properties	Soil depth (cm)				
	0–15	15–30	30–60	60–90	90–120
Sand (%)	17.6	17.1	16.1	15.8	15.0
Silt (%)	39.9	40.3	40.7	40.3	38.9
Clay (%)	42.5	42.6	43.2	43.9	46.1
Bulk density (Mg m ⁻³)	1.40	1.42	1.48	1.50	1.50
pH (1:2.5)	7.1	7.1	7.4	7.5	7.7
E.C. (1:2.5)(dSm ⁻¹)	0.40	0.41	0.39	0.38	0.38
Water retention (%)					
33 kPa	32.4	33.0	33.2	33.5	33.5
1500 kPa	17.5	17.6	17.6	17.7	17.7
Organic carbon (%)	0.69	0.54	0.51	0.49	0.42
Carbon pool (Mg ha ⁻¹)	14.5	11.5	22.6	22.1	18.9
C.E.C. (meq 100 g ⁻¹ soil)	37.1	38.6	39.3	39.0	41.1
Avail. N (kg ha ⁻¹)	242	228	—	—	—
Avail. P ₂ O ₅ (kg ha ⁻¹)	22.4	20.3	—	—	—
Avail. K ₂ O (kg ha ⁻¹)	471	465	—	—	—
Zinc (ppm)	0.36	0.37	—	—	—
Cu (ppm)	1.59	1.66	—	—	—
Fe (ppm)	5.4	5.2	—	—	—
Mn (ppm)	3.8	3.7	—	—	—
S (ppm)	4.6	4.5	—	—	—
AWC (cm)	3.1	3.3	6.9	7.1	7.1

Land capability sub-class – IIles

Irrigability class – 3st

AWC – available water capacity.

Table 13 Properties of a Vertisol at Hoshangabad site, MP state, India

Soil properties	Soil depth (cm)				
	0–15	15–30	30–60	60–90	90–120
Sand (%)	23.2	22.0	22.0	21.0	21.0
Silt (%)	33.3	33.5	32.3	29.8	29.0
Clay (%)	43.5	44.5	45.7	49.2	50.0
Bulk density (Mg m^{-3})	1.42	1.45	1.48	1.58	1.59
pH (1:2.5)	7.7	7.9	7.8	7.9	8.0
E.C. (1:2.5)(dSm^{-1})	0.2	0.3	0.3	0.3	0.3
Water retention (%)	32.5	33.1	33.2	34.6	33.7
1500 kPa	18.6	18.7	18.9	20.0	20.1
Organic carbon (%)	0.57	0.49	0.45	0.34	0.32
Carbon pool (Mg ha^{-1})	12.1	10.7	20.0	16.1	15.3
C.E.C. ($\text{meq } 100 \text{ g}^{-1}$ soil)	36.9	36.0	36.2	35.5	35.4
Avail. N (kg ha^{-1})	23.0	22.5	—	—	—
Avail. P_2O_5 (kg ha^{-1})	25.4	25.9	—	—	—
Avail. K_2O (kg ha^{-1})	57.1	56.5	—	—	—
Zinc (ppm)	0.5	0.4	—	—	—
S (ppm)	3.5	2.8	—	—	—
AWC (cm)	3.0	3.1	6.3	6.9	6.5

Land capability sub-class – IIIs

Irrigability class – 3st

AWC – available water capacity.

Table 14 Effect of raised/sunken bed system on yield of wheat and chickpea

Treatment	Yield (Mg ha^{-1})	
	Wheat	Chickpea
Raised bed	—	2.0
Sunken bed	3.6	—
Flat bed	3.5	1.9

Table 15 Residual effect of integrated nutrient management (INMP) on yield of wheat and gram at Narsinghpur

Treatments	Wheat		Chickpea	
	Grain yield (Mg ha^{-1})	Percentage increase over the farmers' practice	Grain yield (Mg ha^{-1})	Percentage increase over the farmers' practice
Farmers practice (FP)	1.9	—	1.3	—
INMP	3.1	60.8	2.2	73.0
GRD	2.6	36.6	1.9	45.5

GRD = General recommended dose.

Table 16 Results of soybean-pigeon pea intercropping

Treatment	Yield (Mg ha^{-1})		Pigeon pea equivalent yield (Mg ha^{-1})	Gross income (Rs. ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Benefit: cost ratio
	Soybean	Pigeon pea					
Sole soybean (JS-335)	1.5	—	0.8	16,060	7,842	8,218	1.05: 1
Sole pigeon pea (JKM-7)	—	1.3	1.3	25,600	6,471	19,129	2.97: 1
Soybean + pigeon pea (4:2)	1.2	1.2	1.8	36,080	8,460	27,620	3.27: 1

Table 17 Results of fish-wheat/gram rotation

Treatment	Production (Mg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net return (Rs. ha^{-1})
Fish	1.1	12,576	27,500	14,924
Wheat	2.5	7,092	14,880	7,788
Fish	1.1	12,576	27,500	14,924
Chickpea	1.9	6,616	21,737	15,121
Total revenue (Rs.)		19,192	49,237	30,045

Table 18 Multiplication of breeder seeds in "seed villages"

a. Narsinghpur site			
Village	Average of three villages (Dangidhana, Murlipodi, Bagpodi)		
	2000–2001	2001–2002	2002–2003
Soybean	0.40	7.2	21.5
Wheat	0.40	40.9	55.7
Chickpea	0.35	24.6	28.5
b. Hoshangabad site			
Village	Average of three villages (Mongwari, Bahrakhedi, Dolaria)		
	2000–2001	2001–2002	2002–2003
Soybean	—	1.0	15.0
Wheat	0.4	27.2	30.6
Chickpea	—	0.6	13.2

Table 19 Average yield of crops in "seed villages"

a. Narsinghpur site			
Village	Average of three villages (Mg ha ⁻¹) (Dangidhana, Murlipodi, Bagpodi)		
	2000–2001	2001–2002	2002–2003
Soybean	1.0	1.8	2.1
Wheat	1.9	2.6	2.6
Chickpea	1.3	1.8	1.8
b. Hoshangabad site			
Village	Average of three villages (Mg ha ⁻¹) (Mongvari, Baltrakhedi, Dolaria)		
	2000–2001	2001–2002	2002–2003
Soybean	1.0	1.1	1.5
Wheat	1.4	2.7	3.1
Chickpea	1.2	1.4	1.7

6 Conclusions

A community-based participatory operational research project on Alfisols (red soils) of Tamil Nadu in the semi-arid region of India benefited the farming community by adopting rainfed agriculture with adoption of BMPs of dry farming technologies. The on-farm demonstrations revealed the beneficial impacts on soil quality and agronomic production of the BMPs comprising the following components: (1) disc plowing during summer, (2) establishing tied ridges with mulch, (3) application of press-mud compost enriched with rock phosphate, (4) intercropping of pigeon pea as main crop and other pulses and groundnut as intercrop, (5) double cropping with sunnhemp and pulses, (6) diversification of cropping with nutritious minor millets, (7) drip irrigation for high-value vegetable crops, (8) agriculture-centered income-generating activities for self-help groups of farm women, (9) utility of soil testing and use of "soil health card" for monitoring soil productivity and sustainable agriculture, and (10) introduction of arid horticulture.

Soil and rainwater management are the key factors for increasing the production potential of Vertisols in the high rainfall region of Central India. Land treatments (RSBS, ridges and furrows, broad bed and furrows) increased in situ soil moisture conservation, minimized runoff, and increased the yield of principal crops grown in the region (soybean, wheat, chickpea, and rice). INM based on soil testing and application of well-decomposed FYM and biofertilizers increased the yield of soybean and wheat. Intercropping with soybean and pigeon pea in 4:2 ratio was a successful cropping system over the traditional monocropping of soybean. Aqua-agriculture

rather than following in the monsoon season is a feasible system in place of traditional monocropping in winter season. The "seed village" model for decentralized production and distribution of quality seeds of HYV of crops among the farming community proved successful in increasing the average yield of crops in the project villages.

Soil fertility and on-farm water management are crucial to sustainability of intensive agricultural production systems of Punjab. On-farm demonstration studies indicated several viable alternatives to the traditional RWS. Substituting rice by maize, cotton, sugarcane were economic and profitable cropping systems. In regions where WT is rising, as in the canal-irrigated area in Faridkot district, replacement of rice with cotton is a viable option. With forest cover of only 5–6% of the total land area in Punjab, agroforestry interventions should form an integral part of long-term land cover and land use management strategy. Incorporating poplar in the rotation with intercrops such as maize, mung bean, wheat, ginger, and turmeric is a suitable agroforestry system.

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Decision Support Systems: Concepts, Progress and Issues – A Review

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Abstract Agriculture is a complex process of air, water, weather, soil, plants, animals and micro-organisms, which are uneven in distribution. Because of the uncertainty and risk associated with agricultural production – due to vulnerability in weather, variability in soil, infestation of pests and insects – some most important decisions based on “what if” depends on the existing knowledge base of current and future physical conditions like soil and climate, yield and prices, crop and area. If the past pattern and exact impact of agriculture-associated resources are known, one can predict the likely occurrences of certain crop-related attributes in advance, so that farmers can put together safeguards by tiding over the controllable attributes, which are likely to have serious impact on crop growth and yield. Thus the quality of decision-making can play an important role in complex and uncertain situations.

Empirical evidence reveals that human judgement and decision-making can be far from optimal and could even deteriorate further with added complexity and stress. Therefore, aiding the deficiencies of human judgement and quality decision-making has been a major focus of research throughout the history particularly with the advancement in electronic processing of data and design of Decision Support System (DSS). DSS can help to reduce uncertainty and improve the decision-making process by providing access to data through procedures and analytical reasoning. Computerized decision support for sustainable agriculture is not new. These systems have been designed to address complex tasks involving agronomic, economic, regulatory, climate change and pollution control, enabling us to match the biological requirements of crop to the physical characteristics of land so that the objective specified by the user is obtained. Most agricultural DSSs aim to help stakeholders realize their strategic aim of securing a competitive advantage through timely decision-making.

While addressing the limitations in current decision support technologies, visionaries and researchers throughout times have talked of exploiting our mass

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