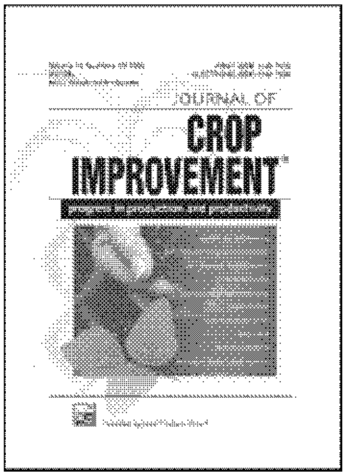

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Sustainable Management of Vertisols in Central India

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Sustainable Management of Vertisols in Central India

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A community-based field operational research project was implemented in the Vertisols of Madhya Pradesh (MP), India, to demonstrate the best management practices (BMPs) of land use and soil-fertility management for enhancing productivity. The raised-sunken bed system (RSBS) of land treatment was used to enhance in situ *rainwater conservation and minimize soil erosion and nutrient losses. Grain yields of wheat (*Triticum aestivum*) and chickpeas (*Cicer arietinum*) were higher in this system than in the flatbed system (FBS) of planting. Soybean (*Glycine max*) yield increased nearly 100% with the ridge-furrow system (RFS) and about 55% in broad-bed and furrow system (BBFS) compared with the FBS. Adoption of integrated nutrient management (INM) based on soil testing increased soybean and wheat yields by 71% over farmers' practice at Narsinghpur, compared with about 100% for soybean and 187% for 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) than either of the monocropping system. An aquaculture 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 chickpeas in the winter season proved successful, and is being adopted in the region. The concepts of 'seed farmers' and 'seed village' were promoted to*

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ensure seed replacement and availability of quality seeds of high-yielding varieties of soybean, chickpea, and wheat. Seed replacement increased mean yield in the participating villages by 30% to 50%.

KEYWORDS *Vertisols, soil conservation, raised sunken bed system, participatory research, integrated nutrient management*

ABBREVIATIONS

AWC	available water capacity
CEC	cation exchange capacity
EC	electrical conductivity
GWT	ground water table
ha	hectare
I	irrigation
INMP	integrated nutrient management practice
Mg	megagram (metricton)
Rs	Indian Rupees

INTRODUCTION

Vertisols (black soils) occupy 7% of the arable lands in the semi-arid tropical regio of India and cover large areas under dry farming in central and southern India (Figure 1). Vertisols are derived from base-rich rocks (basalt) or the related colluvium or alluvium parent materials. These soils have a high clay content (30%–70%), vary in depth (15–200 cm), and exhibit distinct cracking patterns. Vertisols 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 seed-bed 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 (>1000 mm), mainly soybean and maize (*Zea mays*), are prone to temporary waterlogging and anaerobiosis.

In India, about 18 million ha (Mha) of Vertisols (12 Mha in the state of Madhya Pradesh [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 the "Haveli system" of cultivation, leaves the land unutilized and prone to severe erosion and runoff. The low water infiltration rate (3–5 mm/h) is attributed to

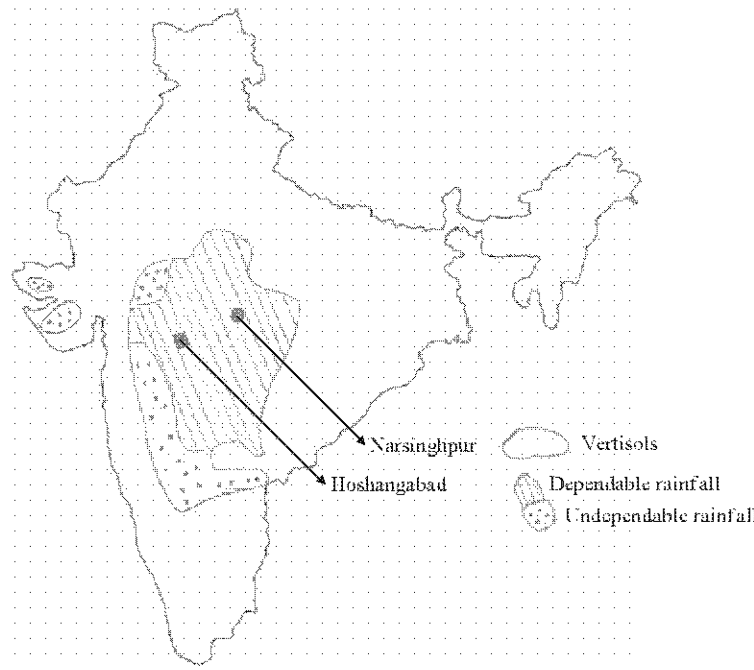


FIGURE 1 Location of the project sites, and distribution of Vertisols in Central India.

high clay content (>40%), which are predominantly expanding-type clay minerals. Through adoption of best management practices (BMPs), there is a vast scope to improve utilization of soil and water resources in the region for intensification of these inherently fertile soils.

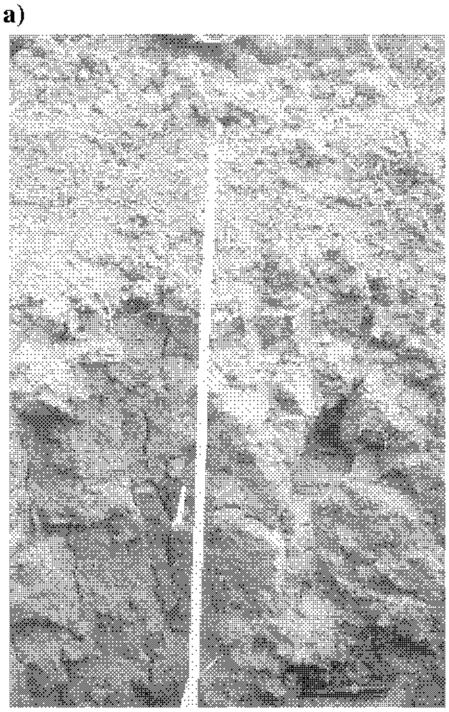
The M.S. Swaminathan Research Foundation (MSSRF), Chennai, India, The Ohio State University, United States, and The Jawaharlal Nehru Agricultural University, Jabalpur, MP, India, implemented a community-based field operational research project. Specific objectives of the project were to: 1) promote adoption 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 integrated nutrient management (INM) practices; and 3) provide training opportunities to researchers, extension workers, and farming communities.

PROJECT SITES

On-farm demonstrations were established on two representative series of Vertisols in Narsinghpur and Hoshangabad districts of MP (Figure 1; MSSRF, 2006). These two districts come under 10.1- (Malwa Plateau, Vindhyan and Narmada Valley) hot, dry, subhumid eco-sub region (Velayutham et al., 1999). The subregion is characterized by subhumid climate with dry summers, mild winters, and ustic soil moisture regime. Temperature ranges from 31°–40°C in summer and 9°–19°C in winter. Annual rainfall ranges from 1000 mm to 1500 mm, and length of the crop-growing period ranges from 150 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 to very gently sloping uplands, and very deep, clayey Chromusterts in the nearly level uplands (Tamgadge et al., 1999)

The groundwater table (GWT) was below 10 m at Narsinghpur, and 5–10 m deep 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 GWT has started declining at the Narsinghpur site at the rate of 15–20 cm per annum, whereas the GWT in 'B' zone of Tawa Command at Hoshangabad is rising at the rate of 20 cm per annum. 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 1 and 2 and Figure 2. Total soil organic carbon (SOC) pool to 120 cm depth was 89.6 Mg ha^{-1} for the soil at 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 K Pa suction or field-moisture capacity (30 to 40% by weight). Total available water capacity to 120 cm depth

a)



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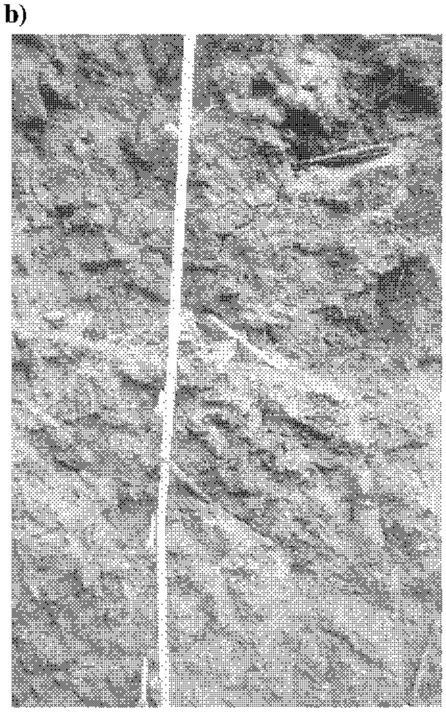

FIGURE 2 Soil profiles: a) Narsinghpur, and b) Hoshangabad.

TABLE 1 Properties of a Vertisol at Narsinghpur Site

	Soil depth (cm)				
Soil properties	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. (me/100g soil)	37.1	38.6	39.3	39.0	41.1
Avail. N (kg/ha)	242	228	–	–	–
Avail. P_2O_5 (kg/ha)	22.4	20.3	–	–	–
Avail. K_2O (kg/ha)	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 IIIes.
Irrigability class, 3rd.
†AWC = available water capacity.

(computed on volumetric basis for the specific depths) was 27.5 cm for the Narsinghpur site and 25.8 cm for the Hoshangabad site (Tables 1, 2).

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 plow 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 twenty farms later. Similarly, ten farmers' fields were selected in three villages (viz., Mongwari, Bhairakhedi, Dolariya) in Hoshangabad district and expanded to forty farms during the second and third years.

LAND TREATMENT AND SOIL CONSERVATION

The raised/sunken bed system (RSBS) of land treatment was established on farmers' fields. The system consists of an array of raised and sunken beds of

TABLE 2 Properties of a Vertisol at Hoshangabad Site

	Soil depth (cm)				
Soil properties	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 (%)					
33 kPa	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. (me/100g soil)	36.9	36.0	36.2	35.5	35.4
Avail. N (kg/ha)	230	225	–	–	–
Avail. P_2O_5 (kg/ha)	25.4	25.9	–	–	–
Avail. K_2O (kg/ha)	571	565	–	–	–
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.

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 intervals 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 (Figure 3) 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 flatbed system (FBS) of cultivation. During the monsoon season, soybeans were sown in the raised bed and rice (*Oryza sativa* L.) in the sunken bed. The results (Table 3) 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.

INTEGRATED PLANT NUTRIENT MANAGEMENT PRACTICE (INMP)

Eight trials were conducted at the Narsinghpur site to demonstrate the effectiveness of INMP for wheat and chickpea. The results (Table 4) indicate that

FIGURE 3 Raised bed-sunken bed system; soybean-rice system.

TABLE 3 Effect of Raised-Sunken Bed System on Yield of Wheat and Chickpea

		Yield (Mg ha^{-1})	
Plots	Treatment	Wheat	Chickpea
1	Raised bed	–	1.95
2	Sunken bed	3.57	–
3	Flat bed	3.45	1.90

TABLE 4 Residual Effect of Integrated Nutrient Management (INMP) on Yield of Wheat and Gram at Narsinghpur

	Wheat		Chickpea	
Treatments	Grain yield (Mg ha^{-1})	% increase over the farmers' practice	Grain yield (Mg ha^{-1})	% 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.

INMP treatment produced the maximum yield in comparison to the general recommended fertilizer alone. With INMP treatment, an additional income of Rs. 6978 ha^{-1} and Rs. 11976 ha^{-1} was obtained for wheat and chickpea, respectively, over the farmers' practice.

TABLE 5 Effect of INMP on Yield of Soybean at Narsinghpur District (Monsoon Season 2002)

Treatment	Yield (Mg ha^{-1})	% Increase over farmers practice
Farmer's Practice	1.4	–
INMP	2.5	71.5
INMP +4 Mg FYM ha^{-1}	2.6	79.0

Similar results were obtained with soybean trials established in fifteen 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; Table 5), which generated an additional income of Rs. 6847/ha compared to the farmers' practice.

HOSHANGABAD SITE

Ten demonstration trials were conducted at the Hoshangabad site to assess the BMPs for wheat var. DL-788-2 in comparison with farmers' practice. The results (Table 6) indicate the high yield (4.0 Mg ha^{-1}) with adoption of BMPs. Similar results were obtained with soybean (Table 7), which indicates the doubling of yield with the adoption of INMP.

Two land configuration treatments, viz., RFS and BBFS, were compared with the FBS of planting soybean. The ridges were formed 15–20 cm high on 0.5% grade (Figure 4). 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. The results (Tables 8 and 9)

TABLE 6 Effect of Full Package of Practices on Wheat at Hoshangabad

Treatments	Yield (Mg ha^{-1}) (Av. of 10 farmers)	% Increase over F.P.
Farmers Practice	1.4	–
Full Package	4.0	187

TABLE 7 Effect of Integrated Plant Nutrient Management on Yield of Soybean at Hoshangabad

Treatment	Soybean yield (Mg ha^{-1}) (Av. of 11 farmers)	% Increase over control
Control	8.7	–
INMP Full Package	17.2	97.6

FIGURE 4 Soybean under ridges and furrows system.

TABLE 8 Effect of Ridge Planting on Soybean Yield

Treatment	Grain yield (Mg ha^{-1}) (Av. of 5 farmers)
Ridge	1.7
Flat bed	0.8
% increase over flat bed	109.3

indicate the advantage of these two systems in improving moisture conservation and soil moisture availability and yield of soybean. Increase in soybean yield was nearly 100% with RFS and 55% with BBFS compared with the farmers' practice. Selvaraju et al. (1999) reported that BBF and

TABLE 9 Yield of Soybean as Influenced by BBF and RF System

Treatment	Yield ($Mg\ ha^{-1}$)	% increase over flat bed system
Flat bed system	1.02	–
Broad bed & Furrow System (BBF)	1.58	54.9
Ridge & Furrow system (RFS)	1.95	91.3

compartmental bunding land configuration could be adopted on Vertisols for better water conservation and crop productivity.

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 10) 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.

One of the improved agronomic practices in rice cultivation is 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 equivalent to those for continuous flooding (Table 11). This demonstration has created awareness among farmers in the region about the benefits of water-conservation technology for growing rice.

AQUA-AGRICULTURE—AN ALTERNATIVE TO MONOCROPPING

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 in 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 (Figure 5) according to the standard management practices. Wheat and chickpea were sown in the same field after fish harvest in October. Fish, wheat, or chickpea rotation in the field increased the net returns considerably more than fallowing during the rainy season and cropping only during the winter (Table 12). The data

TABLE 10 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	16060	7842	8218	1.05: 1
Sole pigeon pea (JKM-7)	–	1.3	1.3	25600	6471	19129	2.97: 1
Soybean + pigeon pea (4:2)	1.2	1.2	1.8	36080	8460	27620	3.27: 1

TABLE 11 Effect of Irrigation Management on Rice Yield

Treatment	Rice yield (Mg ha^{-1})	% increase over check
Continuous flooding	3.50	116
Irrigation at tillering + flowering + grain filling stage	3.75	131

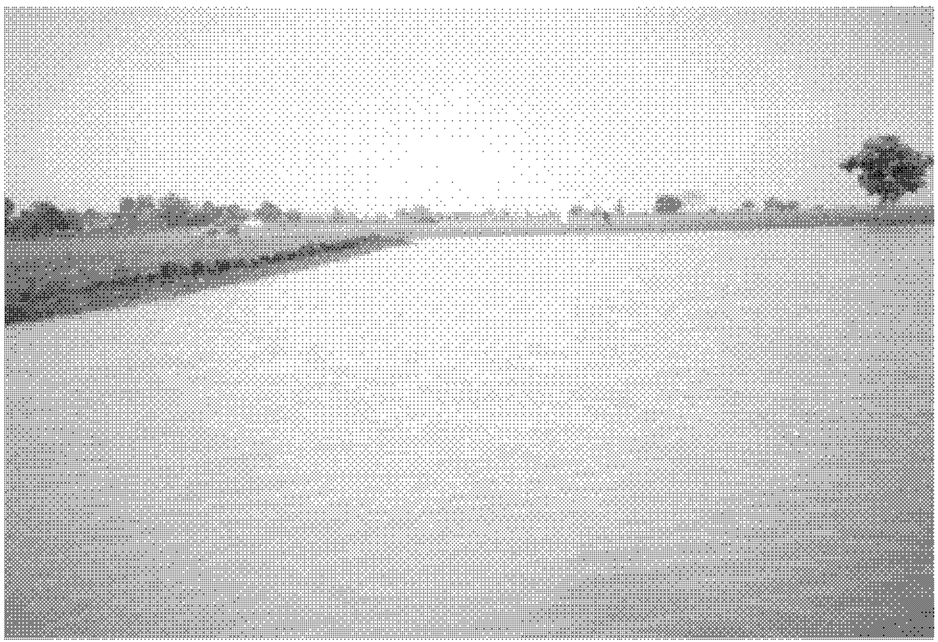

FIGURE 5 Ponded agricultural field for fish culture.

TABLE 12 Results of Fish-Wheat/Gram Rotation

Treatment	Production (Mg ha^{-1})	Cost of cultivation (Rs.)	Gross income (Rs. ha^{-1})	Net return (Rs. ha^{-1})
Fish	1.1	12576	27500	14924
Wheat	2.5	7092	14880	7788
Fish	1.1	12576	27500	14924
Chickpea	1.9	6616	21737	15121
		Total: 19192	**49237**	**30045**

highlight the feasibility and economic advantage of adopting aqua-agriculture in the vast Vertisol region of MP. The demonstration trials of this type conducted in farmers' fields provided excellent loci for dissemination of this important technology.

In the villages, ponds serve as common property resources. Two old, unutilized ponds (tanks) were cleaned by the farmers and, with the assistance

TABLE 13 Results of Water Harvesting and Fish Culture and Soybean Wheat/Gram Rotation

Land Use	Production (Mg ha^{-1})	Cost of Cultivation (Rs.)	Gross income (Rs. ha^{-1})	Net return (Rs. ha^{-1})
Fish culture (0.15 ha)	0.450 Mg/ W.H. tank	5576	9000	3424
Soybean	1.8	8542	18543	10000
Wheat	2.8	6949	16830	9880
	Total: 21067		**44373**	**23304**
Fish culture (0.15 ha)	0.38 Mg/ W.H. tank	5576	7600	2024
Soybean	1.7	8592	18070	9477
Chickpea	2.0	6531	225470	16008
	Total: 20700		**28210**	**27509**

W.H. = water harvest.

of the project staff, the farmers took up fish culture after treating the pond with lime and superphosphate. Fresh cow dung and oilcakes were used daily as fish feed. After harvest of fish, water in the pond was used for pre-sowing irrigation for cultivation of wheat and chickpea. The returns (Table 13) demonstrate the economic advantage of this diversified production system, in the form of aquaculture in tanks in rainy season and crop growing with the harvested water in the subsequent winter season.

INTEGRATED RESOURCE MANAGEMENT OF CROPPING SYSTEMS

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 seeding/ transplanting [I_0], moderate moisture regime [I_1] and optimum moisture regime [I_2]) in combination with nine nutrient sources (S_1 to 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 & 45 DAS	Irrigation at 21, 45, 75 & 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

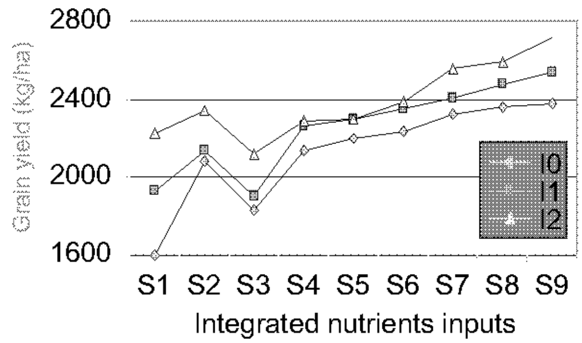

FIGURE 6 Grain yield of soybean (kg ha^{-1}).

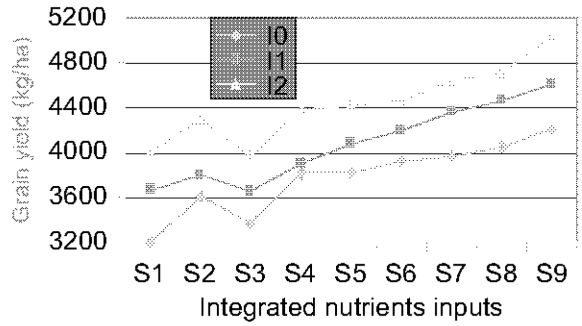

FIGURE 7 Grain yield of wheat (kg ha^{-1}).

(S_6); S_6 + Zn @ 10 kg zinc sulfate/ha (S_7); S_6 + Mo as ammonium molybdate @ 0.5 kg ha^{-1} (S_8), and S_6 + Zn + Mo (S_9).

The grain yields of soybean and wheat are given in Figures 6 and 7, respectively. 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 in other treatments. The treatment combination I_2 S_9 (optimum moisture level and integrated nutrient sources) was the best option for increasing grain yield of both crops.

'SEED VILLAGE' CONCEPT FOR SEED REPLACEMENT

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 make seed replacement by all farmers in the village provides the best quality seed delivery system at the local level. The project staff assisted this process in the selected villages

TABLE 14 Multiplication of Seeds of High Yielding Varieties in 'Seed Villages.'

	Narsinghpur Site		
	Mean of three villages (Dangidhana, Murlipodi, Bagpodi)		
Village	2000–2001	2001–2002	2002–2003
Seed replacement (Breeder seed) in three villages (Mg)			
Soybean	0.40	7.2	21.5
Wheat	0.40	40.9	55.7
Chickpea	0.35	24.6	28.5
	Hoshangabad Site		
	Mean of three villages (Mongwari, Baihrakhedi, Dolaria)		
Village	2000–2001	2001–2002	2002–2003
Seed replacement (Breeder seed) in three villages (Mg)			
Soybean	–	1.0	15.0
Wheat	0.4	27.2	30.6
Chickpea	–	0.6	13.2

and the impact of seed replacement and the increases in mean yield in the villages are given in Tables 14 and 15, respectively. In three years, the production and distribution of HYVs of crops increased the mean yields 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.

CONCLUSIONS

Soil and rainwater management are the key factors for increasing the production potential of Vertisols in the high-rainfall region of central India. The farmer participatory operational research project in the villages proved successful in demonstrating best management practices, such as proper land configurations and soil fertility enhancement. Land treatments (raised-sunken bed system, 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). Integrated nutrient management based on soil testing and application of well-decomposed farmyard manure and biofertilizers increased the yield of soybean and wheat. Intercropping with soybean and pigeon pea in 4:2 ratio was a superior cropping system to the traditional monocropping of soybean.

TABLE 15 Mean Yield of Crops in 'Seed Villages.'

	Narsinghpur site		
	Mean of three villages (Dangidhana, Murlipodi, Bagpodi)		
Village	2000–2001	2001–2002	2002–2003
Productivity (Mg ha^{-1})			
Soybean	1.0	1.8	2.1
Wheat	1.9	2.6	2.6
Chickpea	1.3	1.8	1.8
	Hoshangabad site		
	Mean of three villages (Mongwari, Baihrakhedi, Dolaria)		
Village	2000–2001	2001–2002	2002–2003
Productivity (Mg ha^{-1})			
Soybean	1.0	1.1	1.5
Wheat	1.4	2.7	3.1
Chickpea	1.2	1.4	1.7

The concept of 'seed village' for decentralized production and distribution of quality seeds of high-yielding varieties of crops among the farming community proved successful in increasing the mean yield of crops in the project villages. Aquaculture rather than fallow during the monsoon season is a feasible aqua-agriculture system for the region.

REFERENCES

M.S. Swaminathan Research Foundation (MSSRF). 2006. Sustainable management of natural resources for food security and environmental quality. Project achievements. Chennai, India: M.S. Swaminathan Research Foundation.

Murthy, R.S., L.R. Hirekarur, S.B. Deshpande, B. Venkat Rao, and K.S. Sankaranarayana, eds. 1981. *Benchmark soils of India*. Nagpur, India: National Bureau of Soil Survey and Land Use Planning.

Selvaraju, R., P. Subbian, A. Balasubramanian, and R. Lal. 1999. Land configuration and soil nutrient management options for sustainable crop production on Alfisols and Vertisols of southern peninsular India. *Soil & Tillage Res*. 52:203–216.

Swindale, L.D. 1982. Distribution and use of arable soils in the semi-arid tropics. In *Managing Soils Resources—Plenary Session Papers,* 67–100. Proc. 12^{th} Intl. Congress of Soil Science, February 1982, New Delhi, India.

Tamgadge, D.B., K.S. Gajbhiye, M. Velayutham, and G.S. Kaushal. 1999. *Soil series of Madhya Pradesh*. Pubn. No. 78. Bhopal, India: National Bureau of Soil

Survey and Land Use Planning, Indian Council of Agricultural Research in co-operation with Dept. of Agriculture, Govt. of Madhya Pradesh, Bhopal.

Velayutham, M., D.K. Mandal, M. Champa, and J. Sehgal. 1999. *Agro-ecological sub-regions of India for planning and development* Pubn. No. 25. Nagpur, India: National Bureau of Soil Survey and Land Use Planning.

Venkateswarlu, J. 1987. Efficient resource management systems for drylands of India. *Advances in Soil Science* 7:165–221.