Improving Management of Natural Resources for Sustainable Rainfed Agriculture in Ringnodia Micro-watershed

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Abstract

The current productivity of rainfed lands in Madhya Pradesh, India is about 1.0 t ha^{-1} although there is scope to obtain >3 t ha^{-1}. To assess and evaluate the potential of improved soil, water, and nutrient management options through integrated watershed management at Ringnodia in Indore in western Madhya Pradesh, a micro-watershed of 390 ha was delineated. Soybean is a major crop during the rainy season and yield of <1 t ha^{-1} is obtained in the micro-watershed. Landholdings in the watershed are generally small. The input use is low with little soil and water conservation measures in vogue among farmers. About 30–40% of the total rainfall is lost through runoff, carrying productive soils and nutrients while crops experienced drought stress in the rainy as well as postrainy seasons. With a critical advisory support from scientists, the watershed farmers could augment water storage capacity in the village through construction of percolation/storage tanks and renovation of existing ponds. For safe disposal of water from the watershed, waterways were developed and wire mesh bound boulder structures were constructed to reduce soil loss and runoff. These water storage structures could store up to 30 ha-m water representing about 70% of total runoff from 100 ha cultivated area and thus reduce runoff and soil losses. This increased groundwater recharge, which manifested in increased water table in most wells including the abandoned ones.

The scenario analysis suggested various cropping options for enhanced yield with limited irrigation (soybean-wheat) or under rainfed conditions (pigeonpea/sorghum intercrop). Sorghum/pigeonpea intercrop was, however, less popular amongst the farmers. The introduction of extra-short-duration pigeonpea opened avenues for diversification and its adoption is likely to increase. Under rainfed conditions, double cropping could be practiced in two out of three postrainy seasons. Soybean yields increased marginally by gypsum application and also by planting on mini-ridges. The medium-duration chickpea cultivar JG 218 gave higher yield than short-duration cultivars ICCV 2 and ICCC 37 indicating sufficient moisture for the traditional types. Pests were the major yield reducers in soybean and adoption of integrated pest management options nearly tripled soybean yield.

In another micro-watershed at the College of Agriculture, Indore interaction between land and water conservation measures and efficient cropping systems was examined. Soybean/pigeonpea strip crop and soybean-wheat systems were more productive than soybean-chickpea and soybean-linseed systems. Chickpea and wheat could easily be established with minimum tillage when planted in moist seed zone at 15 cm depth after the harvest of soybean.

The state of Madhya Pradesh comprises about 14% of the total rainfed area of India. Soybean-based production systems dominate the agricultural scenario and have appreciably improved the economic status of farmers of rainfed areas of the state. Soybean is grown in about 4 million ha representing 75% of total soybean area in India. It fits well in the double cropping pattern with wheat and

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other rainfed crops. The introduction of soybean in the state in the 1970s has substantially minimized the incidence of rainy season-fallows and thus directly contributed to sustainability of rainfed agriculture. Since 1987, when the soybean variety JS 335 was released by Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Indore, Madhya Pradesh and improved production technology was available, soybean area increased fourfold and production fivefold. Soybean has greater tolerance to waterlogging than most other crops including cereals grown earlier in the region, which perhaps is the single most important reason for its widespread and rapid adoption.

Although the production of soybean is increasing due to substantial increases in area under the crop and its yield, there is still a large yield gap of about 1.2 t ha^{-1} that needs to be bridged (Singh et al. 2001). Soybean area in India is likely to increase to 10 million ha by 2010, a larger portion of which would be in Madhya Pradesh. With intensification of soybean production systems, about 20 million t of soybean can be produced. Unfortunately, at the current level of productivity, there is appreciable underutilization of land, water, nutrients, and climatic resources. Well-documented congruent relational data sets are needed on water balances, nutrient turnover, weather and crop development interaction, and seed viability to first understand and to tackle the problems associated with the low productivity and unsustainability. There are a number of socioeconomic and technological constraints that are responsible for low yields of soybean, resolution of which in integrated fashion can help in bridging the gap between the realizable and realized yields. This is possible through a holistic management of natural resources of soil, water, biotic, abiotic, and socioeconomic constraints.

The research partnership between JNKVV and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India primarily focused on enhancing productivity of the soybean-based production systems. It also covered other aspects of enhancing farm productivity and sustainability such as diversification and crop intensification. The partners identified two benchmark watershed sites, one at Ringnodia village in Sanwer Tahsil of Indore district for on-farm strategic and applied research, and another at the College of Agriculture, Indore for conducting on-station strategic research.

Ringnodia Micro-watershed

Characterization

Site selection

Ringnodia, a 390-ha micro-watershed, is a part of the National Watershed Development Project for Rainfed Areas (NWDPRA), Solsinda, located at 20 km from Indore city (22°51’ N and 75°51’ E) on Indore-Ujjain highway at an altitude of about 540 m above mean sea level (Fig. 1). The watershed is located in the middle and lower reaches of Khan River. The topography of the Ringnodia micro-watershed can be divided into three sections: a recharge zone of 18.2 ha with a slope of 8% or more, a transition zone with slope of 2–8%, and a cultivated area of 327 ha with a slope of 2% or less, comprising medium to deep Vertisols.

This watershed was selected because the cropping intensity was very low (<130%), the rainy season crop yield was low (<1 t ha^{-1}), and irrigated area was <30% (mainly through tube wells and open wells). Due to lack of soil and water conservation measures most of the runoff water eroded the valuable productive lands. The watershed had two ponds that were in dilapidated state and stored very little water due to silting and heavily breached bunds. While lack of water conservation and soil erosion due to high velocity runoff in the transition zone was a major problem in the upper reaches of the watershed, waterlogging was common in the lower reaches of the watershed. A few main watercourses had developed from the several field washes that carried the runoff water towards the lower reaches, forming deep gullies. In the postrainy season, crops were grown on <30% area and generally suffered from drought.

Weather

The mean annual rainfall at Indore is about 960 mm, a major portion of which is received between 25 and 41 standard meteorological week (SMW) (Fig. 2). The rate of evaporation (mm day^{-1}) increases steadily from the 2nd SMW and attains a peak during the 21st SMW,

Figure 1. Location map of Ringnodia micro-watershed in Indore district of Madhya Pradesh, India.

and thereafter, shows a steep decline up to 29^{th} SMW, and a gradual decline up to 37^{th} SMW. The rainfall and evaporation patterns showed that the period between 26^{th} and 37^{th} SMW is surplus water period. Sowing during the rainy season is usually taken up from the 23^{rd} SMW.

At Ringnodia, rainfall was near normal in 1999 whereas it was 44% less in 2000 and 28% less in 2001 (Fig. 3). In 2000, the beginning of the rainy season was considerably delayed and there were very little rains after 15 August; hence, the postrainy season crops could be grown in <10% area only. The beginning of the rainy season was normal in 2001. Further, about 70 mm rainfall in October, after the harvest of soybean, helped in sowing the postrainy season crops.

Soils

The soils of the Ringnodia micro-watershed are shallow to deep black with variable depth (~0.5 to >0.9 m depth). They occur on bare hill slopes to flat topography. The cultivated soils are mostly clay loam in texture with high moisture retention capacity, normal to somewhat alkaline in reaction (soil pH 7.5–9.3), and electrical conductivity (EC) values <1.00 dS m^{-1} at 25°C for most soils indicating normal soils. The soils in general were low to medium in soil fertility status with respect to available nitrogen (N), phosphorus (P), and sulfur (S), while they were high in potassium (K) content.

The deep soils (>0.9 m) hold about 225 mm plant available water to a meter depth. The soils of watershed are classified into six soil series:

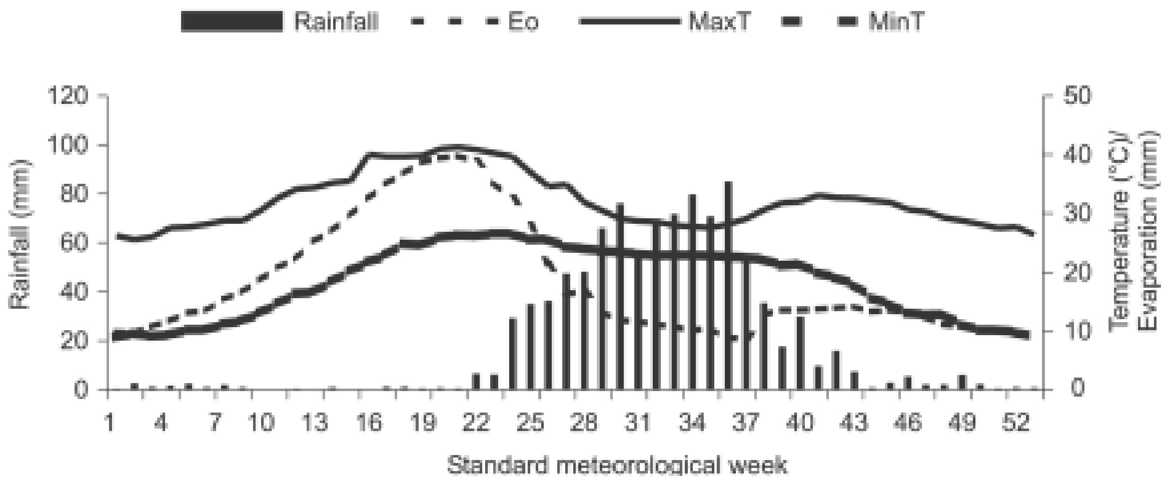

Figure 2. Weather at Indore during 1971–95.

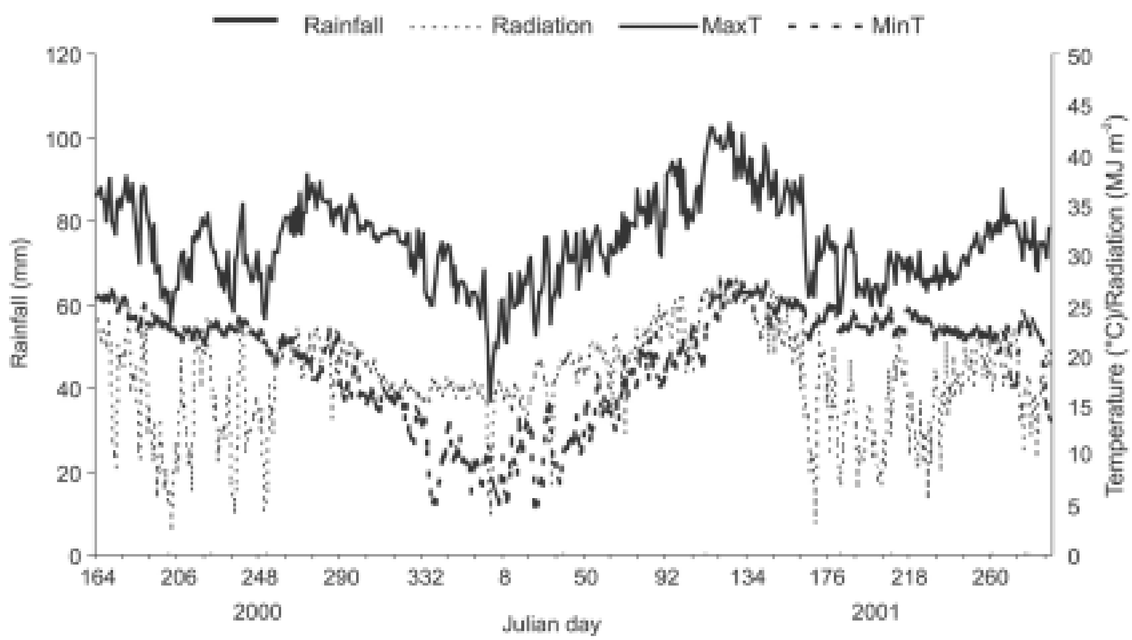

Figure 3. Daily weather during 2000–01 at Ringnodia micro-watershed recorded through automatic weather station.

Panchdaria, Runija, Kamliakheri, Sarol, Baloda, and Malikheri. The deep black soils belong to Sarol and Baloda series, which comprise members of fine montmorillonitic hyperthermic family of Vertic Ustochrepts and Pellusterts, respectively. The shallow soils belong to fine clayey montmorillonitic hyperthermic family of Lithic Ustochrepts.

Land use pattern

Soybean or soybean mixed with a small population of maize was the dominant cropping system during the rainy season. There was very little rainy season fallow. This is in contrast to Lalatora watershed in Vidisha district of Madhya Pradesh, where soybean was generally grown only on irrigable lands as prospects of an irrigated postrainy season crop were assured (Vadivelu et al. 2001). However, unlike the previous rainy seasons, in 2001 there was considerable diversification with other crops such as sorghum, groundnut, pigeonpea (ICPL 88039, JA 4, and local), vegetables, sole maize, and green fodder crops. There was a noticable increase in sorghum area which was attributable to shortage of cereal grain for domestic consumption as most farmers could not take wheat crop in the preceding postrainy season. This is how farmers seem to adjust their cropping patterns to drought conditions in the region.

The rains during September/October have a strong bearing on the prospects of postrainy season crops. In 2000, there was scanty rainfall (<12 mm) in September/October and hence the area under the postrainy season crops was drastically reduced. Some farmers whose tube wells had water managed to establish chickpea and wheat crops. In 1999 and 2001, there were good rains during September and October, which facilitated planting of wheat and chickpea as well as potato in some areas.

Socioeconomic profile

The village has a total population of 855 persons, which includes 435 males, 420 females (466 adults and 389 children). Literacy is about 40%. Agriculture provides the major source of income for 56% of the villagers. They also depend on livestock and poultry, and work in the nearby industries. The landholding in the village varies from >4 ha for the large landholders constituting about 9% of the total farmers, 2 to 4 ha for medium landholders (26%), and <2 ha for small landholders (65%).

The gross annual family income from all sources was US$4000 for the large landholders, US$3200 for the medium landholders, and less than US$2800 for the small landholders. The medium and small landholders also depended on other sources of income such as working as farm labor. There were 14 tractors, 14 cultivators, 10 disc harrows, 7 seed drills, 10 potato planters, 50 sprayers, and 50 threshers in the village. Livestock was maintained by all categories of farmers. There were 143 buffaloes, 59 cows, 92 oxen, and 60 goats in the village. The large landholders spent about 32% of income on agricultural inputs and management of crops, whereas medium and small landholders spent only about 10%. The village had 14 open wells and 19 tube wells, and two silted ponds (prior to our intervention) spread in about 9 ha area.

Major constraints identified through participatory rural appraisal

Through a participatory rural appraisal (PRA) the following constraints were identified:

- Poor resource base (poor soil fertility) and lack of awareness and adoption of improved land and water management practices.
- Water scarcity as a consequence of poor rainwater management practices.
- Less crop diversification.
- Temporary waterlogging on flat lands in lower reaches during the rainy season.
- Soil erosion in the transition zone during the rainy season. Silt loaded runoff in the initial stages of seedling establishment adversely affected soybean crop in the lower reaches.
- Lack of credit to buy quality seeds and other inputs.
- Lack of awareness about practicing improved package of practices, e.g., seed treatment with fungicide and *Rhizobium* culture, recommended fertilizer doses, method of fertilizer application, plant protection measures, and weed management practices.
- Absentee landlordism: some farmers were living in Indore city and thus were unable to give adequate attention to crop management.

Development of Ringnodia micro-watershed

Prior to undertaking any development works in the watershed, most of the runoff originating in the hillock region used to flow through the cultivated area. This water flowing at a great velocity carried considerable soil to the crops in the lower reaches. Soybean crop being sensitive to such deposition in the early stages (Sullivan et al. 2001) was adversely affected. The turbid water eventually reached the ponds and over the years reduced their capacity to store water to the extent that these could barely store 10% of the total runoff. As the storage capacity of these ponds had become very limited, this water used to eventually flow wildly out of the village and join main watercourses to Solsinda and Katkaya Nala (Fig. 4), and eventually to Khan river that joins Kshipra river at Ujjain. In general, the watershed was having fern type catchments. In this type of catchment, runoff is more since discharge is spread over a longer period.

Land and water conservation measures

To conserve natural resources of water and soil, the following measures were undertaken:

- Participatory rural appraisal and topographic survey of the watershed and its instrumentation for undertaking developmental works were completed. A watershed committee has been formed to mobilize and motivate farmers to enlist their participation in the developmental works.
- Storage structures/percolation tanks were constructed in three sections (Table 1) covering about 0.3 km in early 2000 for recharging groundwater and protecting the cultivated area from flooding in the lower reaches. These structures received about 80% of the rainfall as runoff from about 9.5 ha hillock area. It was, however, realized during the rainy season 2000 that the storage structures could protect only a small part of the watershed (<2 ha) as large gullies were still forming in the cultivated area due to runoff from an adjacent 7.5 ha hillock area. A 0.3-km long diversion bund in an area contiguous to the storage structures was therefore, constructed prior to the rainy season 2001 to reduce velocity of runoff from this barren hillock region and safely dispose it through the watercourses.
- Twenty-five loose and wire mesh bound boulder structures were constructed to reduce velocity of runoff and retain silt upstream and thereby stabilize watercourses.
- Waterways were improved for safe disposal of water from fields.
- A temporary bund was constructed on the main waterway to increase discharge to ponds.
- Deepening, shaping, strengthening by pitching, and repair of the breached bunds of village ponds were carried out to increase storage capacity. These ponds can now store about 20–30 ha-m water representing about 75% of the total runoff of the 100-ha catchment in the upper reaches in a normal rainfall year (Fig. 5). The de-silting of the ponds served twin purposes: enhancement of storage capacity of ponds, and application of the silt in fields for improving soil fertility.

All these works were undertaken in a farmer participatory mode with financial assistance of US$4000 from the District Collector, Indore, under the XI Finance Commission. These works also created lot of awareness and interest in soil and water conservation works among farmers of the nearby villages and extension agencies operating in the area.

Quantification of the benefits of soil and water conservation

In the rainy season 2000, the runoff from the treated and untreated areas was small (<15 mm) and the differences were marginal. The construction of a 0.3-km long diversion bund in 2001 resulted in 34% reduction in runoff. Most of the runoff had occurred prior to planting of the rainy season crops.

In 2001, soil loss was high (about 0.9 t ha^{-1}) in the untreated area compared to 0.1 t ha^{-1} in the treated area. The organic carbon content in the silt lost through runoff from the treated and untreated areas was 0.76% and 0.84% and available N was 0.014% and 0.015%, respectively. The organic carbon loss due to runoff was 7.6 kg ha^{-1} from the untreated area and 1.14 kg ha^{-1} from the treated area. The N loss due to runoff was less than 1 kg ha^{-1} from both areas.

There was no appreciable difference in water balance and the water use efficiency between the

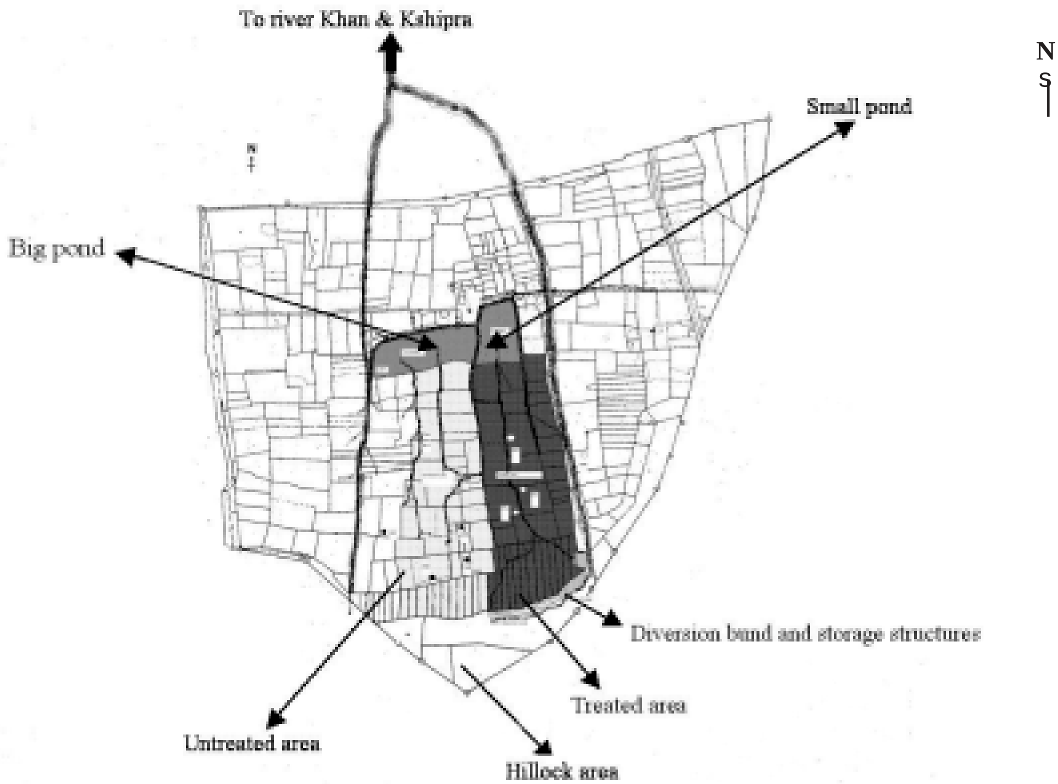

Figure 4. Ringnodia micro-watershed map.
(Note: The dark area is treated area and gray adjacent area is untreated control, both extending up to pond area.)

treated and untreated areas. The water use ranged from 329 mm for shallow soils to 400 mm for deep soils in the treated area. Since there was very little runoff during the cropping period (no waterlogging or silt deposition), the differences due to land and soil management were unlikely to have occurred between the treated and untreated areas. The water use efficiency ranged from 3.5 kg mm^{-1} ha^{-1} in shallow soils in the treated area to 7.6 kg mm^{-1} ha^{-1} in medium soils in the untreated area.

The storage structures constructed in the transition zone increased water table of the wells (groundwater recharge) (Fig. 6). The difference in the water table across wells near to the storage structure and farthest point was up to 3 m when measured with respect to uniform reference level.

Strategic research on best-bet options

Devising efficient cropping options

The development and application of simulation models of crops is well established in studying crop response to changes in genotype, cultivar, soil, weather, climatic patterns, and management practices. To identify best production system, we have generated scenarios of crop production using the APSIM (Agricultural Production Systems Simulator) (McCown et al. 1996). This model allows modeling of crop and pasture production, residue decomposition, and soil water and nutrient flow to be readily configured to simulate various production systems, including crop sequences and intercropping, and soil

Table 1. Salient features of water storage structures constructed in transition zone at Ringnodia micro-watershed during 1999.

Feature	Segment 1	Segment 2	Segment 3
Area contributing to pond (ha)	4.5	3.5	1.5
Type	Earthen bund	Earthen bund	Earthen bund
Shape	Semi-circular	Trapezoidal	Trapezoidal
Length of bund (m)	110	100	65
Surface area (m^2)	4400	2500	1625
Top width of bund (m)	3.2	3.2	3.2
Storage-capacity (maximum) (ha-cm)	140	80	48
Excavation/earthwork (m^3)	1620	1200	460
Excavation (%)	14.7	12	9.6
Function	Water storage	Percolation	Percolation

Figure 5. Water storage in the renovated big pond in Ringnodia micro-watershed after the first major runoff event in June 2001.

(Note: This existing tank did not store any water due to breached bund and silting prior to our intervention as shown in the inset.)

and crop management to be dynamically simulated using conditional rules.

The long-term scenarios for the 18 growing seasons derived using the APSIM model (McCown et al. 1996, Robertson et al. 2001) suggested that among the rainfed systems, pigeonpea/sorghum intercrop was the most productive cropping system with >5 t ha^{-1} total production and least variable (Fig. 7). In the postrainy season, systems involving partially irrigated wheat were most productive. Indeed, soybean-wheat rotation is practiced in about 64% of the total arable area in the postrainy season in the region. Rainfed cropping systems involving only legumes either as intercrops (soybean/pigeonpea) or sequential crops (soybean-chickpea) were less productive. The introduction of extra-short-duration pigeonpea as intercrop with soybean was not very productive, probably because of its matching life cycle duration with soybean. A provision of limited supplemental irrigation to chickpea could further boost the prospects of only legume-based systems. However, a legume-cereal system should be more appropriate, cost effective, and highly remunerative diversified farming system as it can derive maximum benefit of N-fixing capability of legumes and can meet the farmer's varied requirements of food and fodder.

Diversification with pigeonpea

Very few farmers in the micro-watershed grew pigeonpea as an intercrop with soybean. Thus, pigeonpea observation trials were laid out to introduce pigeonpea (variety JA 4) as a sole crop in the prevailing cropping system at two locations. Also, three trials of soybean/pigeonpea intercropping system were laid out. The 1999 rainy season was slightly adverse for soybean crop as there occurred a long dry spell after sowing and heavy rains during the reproductive period causing a severe setback to its productivity. Pigeonpea crop grown either alone or as an intercrop with soybean could resist these aberrations (Table 2). However, due to operational inconvenience in planting (sowing in different rows posed difficulty with existing planters) and harvesting (due to crops of dissimilar maturity period), farmers did not favor this system. Further, with medium-duration pigeonpea, there was little prospect of a second crop in the postrainy season. It gave <0.3 t ha^{-1} during 2000 due to terminal drought. In 2001 none of the farmers grew soybean/pigeonpea intercrop.

As medium-duration pigeonpea suffers from terminal drought and does not allow double cropping, extra-short-duration pigeonpea genotype ICPL 88039 that matures in 120 days was introduced in the

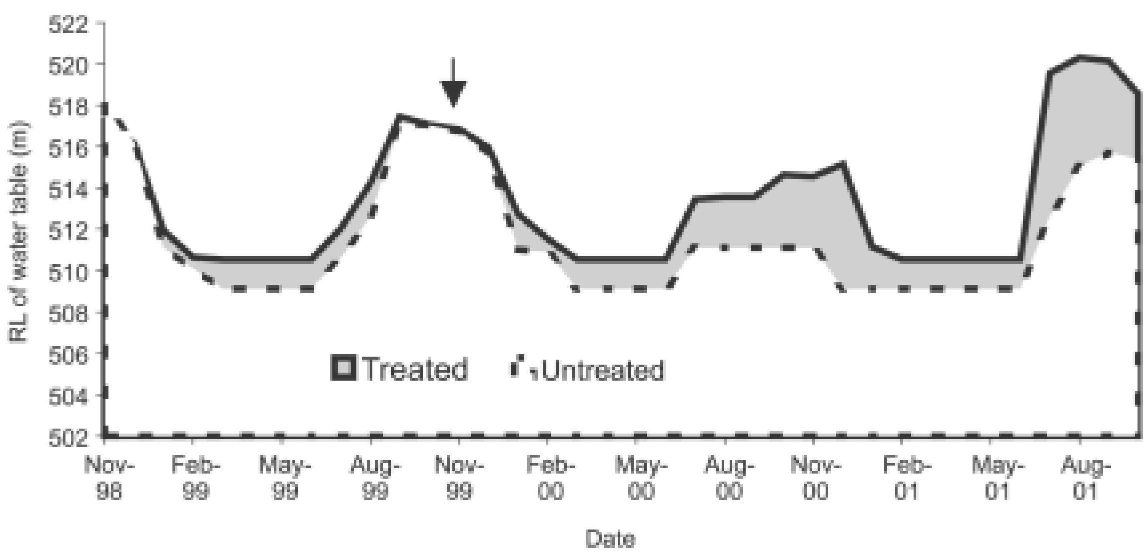

Figure 6. Water table fluctuations in terms of reduced level (RL) in the nearest (treated) and farthest (untreated) wells to the water storage structures in Ringnodia micro-watershed.
(Note: The arrow indicates date of construction of storage structures.)

Table 2. Productivity of soybean and pigeonpea as sole and intercrops in farmers' fields in Ringnodia micro-watershed, rainy season 1999.

Treatment	Yield (kg ha^{-1}) Location 1	Location 2	Location 3	Mean	LER[1]	Gross returns[2] (Rs ha^{-1})
Sole soybean	960	780	765	835	1.0	6680
Soybean/pigeonpea					1.7	18285
Soybean	782	636	652	690		
Pigeonpea	940	826	786	851		
Sole pigeonpea	1330	1140		1239	1.0	18585

1. Land equivalent ratio.
2. Calculated on the basis of price in January 2000.

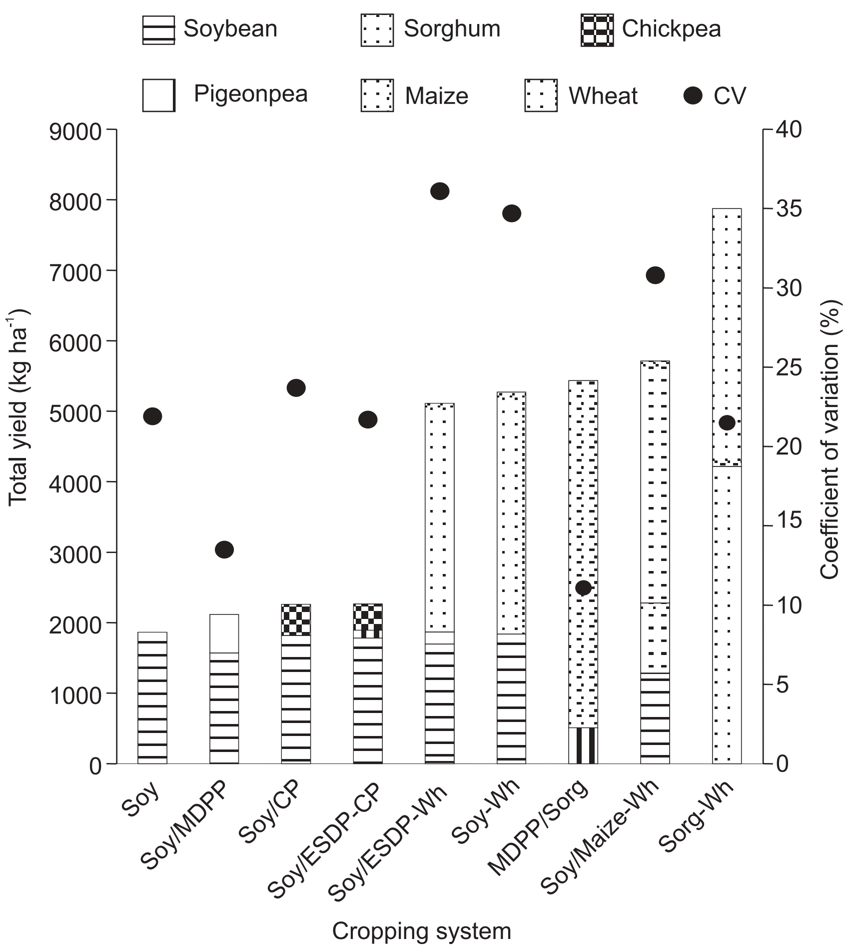

Figure 7. Long-term scenarios (mean of 18 years from 1984–2001) for different cropping system options and coefficient of variation (CV) for Ringnodia micro-watershed.

(Note: Soy = soybean, ESDP = extra-short-duration pigeonpea, MDPP = medium-duration pigeonpea, CP = chickpea, Wh = wheat, - = sequential cropping, / = intercropping.)

watershed with 24 farmers growing the crop in about 0.05-ha plots. The extra-short-duration pigeonpea escaped terminal drought on both shallow (0.62 t ha^{-1}) and deep soils (1.03 t ha^{-1}) and gave higher yield than medium-duration cultivars. There are indications that the adoption of extra-short-duration pigeonpea may increase in near future as not only farmers of Ringnodia but also farmers in adjacent villages who bought seed from Ringnodia farmers chose to continue growing the crop in 2001.

Land configuration

Waterlogging is a major constraint, particularly on flat lands in normal to high rainfall years when there are heavy silt loaded inflows from upper reaches. We evaluated broad-bed and furrows (BBF) landform and found that in spite of below normal rainfall in 2000 season soybean yield from flat landform and BBF was same. However, farmers were reluctant to adopt this measure due to operational difficulties in planting, intercultural operations, and reduced plant population.

Alternatively 5 to 10 cm high 'mini-ridges' were evaluated. These were made using a small duck-foot shaped spade between two tines. While making the ridges, this spade removed pre-emergence weeds and made the soil loose thereby ensuring good plant stand. In 2001, although yield of soybean obtained on mini-ridges was 8.5% greater than the adjacent flat beds, the difference was statistically not significant, probably due to below normal rainfall.

Integrated nutrient management

Five farmers evaluated recommended doses of fertilizer with soybean and found no increase in yields with fertilizer or *Rhizobium* application suggesting that N availability did not limit soybean yield in this watershed. During 2001, 12 farmers evaluated response of soybean to 30 kg S application through 200 kg ha^{-1} gypsum. Application of gypsum increased soybean yields by 70 kg ha^{-1} (5.4% more) over the non-gypsum plots.

Integrated pest management

Insect pest damage was one of the major biotic constraints for the yield gap between the potential and the realized yield in the watershed. Although farmers have access to insecticides they do not spray recommended quantities in time. They required an exposure to integrated pest management (IPM) options so that they could control the pests without depending on high doses of insecticides. A combination of insecticides and herbal preparations like Neemol and cow urine were found to be effective in reducing pest population (Tables 3 and 4). The

Table 3. Girdle beetle damage and semilooper larvae on soybean in farmers' fields at Ringnodia micro-watershed during the rainy season 2000/01[1].

	Girdle beetle damaged plants[2]		Semilooper larvae[2]		
Treatment	Before	After	Before	After	Seed yield (t ha^{-1})
T1	1.10	0.37	0.34	0.28	1.56
T2	0.77	0.57	0.38	0.26	1.24
T3	1.08	0.78	0.48	0.41	1.04
T4	1.88	1.80	0.47	0.70	0.54
SEm	0.06		0.04		0.06
CD at 5%	0.17		0.10		0.19

1. Data is mean of values obtained from seven farmers' fields.
   T1 = Two sprays of Quinalphos 25 EC, 2 ml L^{-1} at 1.0 L ha^{-1}; T2 = One spray of Quinalphos 25 EC, 2 ml L^{-1} at 1.0 L ha^{-1} followed by Neemol spray (20 days after Quinalphos spray); T3 = Two sprays of Neemol at 5 ml L^{-1} (20 days interval) at 2.5 L ha^{-1}; T4 = Absolute control.
2. Number m^{-1} row length at 72 h before and after spray.

Table 4. Effect of integrated pest management on pest control and soybean yield.

Treatment	Girdle beetle damage[1] (%)			Grain yield ($t\ ha^{-1}$)
	33 DAE	45 DAE	Cumulative	
Monocrotophos at 30 & 45 DAE (1 L ha^{-1})	10.6	39.0	24.8	1.71
Neemol at 30 & 45 DAE (1.5 L ha^{-1})	15.4	53.1	34.6	1.56
Cow urine (50 ml L^{-1})	15.2	61.2	38.2	1.40
Control	21.0	76.0	48.5	1.11
SEm	0.85	2.63	1.57	0.077

1. DAE = Days after emergence of soybean crop.

yield increase was up to three times in the IPM plots. The increase in yield was largely due to effective control of girdle beetle and semilooper larvae.

Fruit trees and *Gliricidia* plantation

In a quest for diversification of income sources, planting of several fruit trees such as jack fruit, papaya, custard apple, and *jamun* was encouraged. Each farmer was given two seedlings of each type that were planted in the backyard or on field boundaries. The mean survival of different fruit tree species varied from 40 to 100%. *Jamun* and custard apple were best established. A low rainfall in 2000 affected the survival of other tree species. Thus, there appears to be a scope for introducing selected fruit trees and diversifying farmers' income sources. *Gliricidia* seedlings were distributed among farmers for generating foliage to improve soil N and organic matter. In 2000, *Gliricidia* seedlings failed to survive as they were planted on diversion bund and hillock area where little individual care could be provided and moisture stress was acute.

Technology exchange

The adoption of BBF technology was very low in the Ringnodia micro-watershed as probably farmers were not fully aware of its benefits. To familiarize with the BBF system five farmers of Ringnodia village were taken to a neighboring benchmark site in Lalatora during May 2001. They learned about BBF on deep black soils and its advantages. They also exchanged their views about the features of short-duration soybean Samrat which could be used for double cropping.

Impact on crop productivity

Impact assessment was done in 2001. The data based on sample farmers of Ringnodia micro-watershed, revealed the overall impact of the interventions made with respect to soil and water management (Table 5).

Table 5. Increased productivity ($t\ ha^{-1}$) of important crops grown in Ringnodia micro-watershed based on sample survey.

Landholders	1998/99				2000/01			
	Soybean	Wheat	Chickpea	Potato	Soybean	Wheat	Chickpea	Potato
Small	0.70	1.60	0.50	15.54	0.85	1.68	0.71	18.90
Medium	0.75	2.40	0.60	16.10	0.92	2.51	0.79	19.80
Large	0.80	2.30	0.60	17.00	0.96	2.47	0.80	21.40
Increase (%)					21	6	36	17

College of Agriculture Micro-watershed

Background and treatment details

The productivity of soybean-based cropping systems in Madhya Pradesh is constrained by prolonged wet spells during the months of July and August and dry spells during the reproductive stage of soybean. Inadequate and imbalanced nutrition management practices followed by farmers also contribute to low and unstable productivity of soybean. Other production constraints include weeds, insect pests, and diseases. The strategic research work at the College of Agriculture micro-watershed in Indore was taken up to sustain productivity of soybean-based cropping systems to conserve and optimally utilize natural resources, and to determine soybean cultivar parameters for modeling.

A 2-ha micro-watershed was delineated in the 'C' block of the College of Agriculture farm (22°43' N and 76°54' E, about 540 m above mean sea level), Indore. The soils of the watershed are Vertisols belonging to Sarol series with medium fertility and low organic matter and are more than a meter deep. The plant available water-holding capacity was about 230 mm to a meter depth.

There were two main plots accommodating two land configuration treatments, flat (control) and BBF, and four subplot treatments of cropping systems, soybean (JS 335)-chickpea (JG 218); soybean (JS 335)-linseed (ILS 252); soybean (JS 335)-wheat (Sujata); and soybean (JS 335)/pigeonpea (JA 4) (4:2) strip cropping system. The treatments were laid out in a split plot design. The gross subplot size was 40 m × 15 m. The planting dates were: 4 July 1999, 6 July 2000, and 22 June 2001 for the rainy season crops, soybean and pigeonpea; 26 October 1999 and 10 October 2001 for the postrainy season crops, linseed, chickpea, and wheat. The harvesting dates were October 21 and 25, in 1999 and 2000, respectively, for soybean; 3 January 2000 for pigeonpea; 28 February 2000 for chickpea and linseed; and 23 March 2000 for wheat. There were no postrainy season crops in 2000 due to insufficient moisture in surface layers and the postrainy season crops of 2001 were planted on 6–10 October. The pigeonpea crop planted in 2000 failed due to terminal drought.

Observed and simulated performance

Soybean yields were high (2 t ha^{-1}) in 2001, but in the previous two seasons they were very low. The observed yield was compared with APSIM simulated yield. In 2001, the observed yield and other parameters were very similar to simulated yield (Table 6). However, in the previous two seasons, the observed yield was significantly less than the simulated yield (Fig. 8). This low yield could be attributed to various factors, such as weed incidence and damage by stray cattle. There was only a marginal advantage of about 60 kg ha^{-1} yield of soybean due to planting on BBF, which was statistically not significant. This could be because waterlogging did not occur in any of the seasons.

Table 6. Observed versus APSIM predicted parameters of the phenological stages, yield, and total dry matter of soybean variety JS 335 sown on 22 June 2001.

Parameter	Observed	Predicted
Days to flowering	42	48
Days to maturity	100	99
Yield (t ha^{-1})	1.89	1.94
Total dry matter (t ha^{-1})	5.45	5.19
Harvest index (%)	34.7	37.4

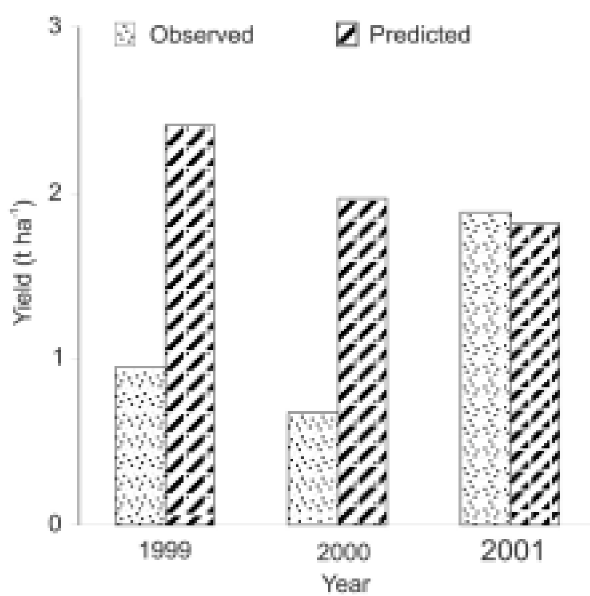

Figure 8. Simulated and observed soybean yields at the College of Agriculture micro-watershed, Indore.

Among the component crops, yield of pigeonpea and wheat was better than that of chickpea and linseed. In 2001, the postrainy season crops of wheat, linseed, and chickpea were planted under zero tillage and rainfed conditions as per the treatments. The establishment and growth of chickpea was better than wheat whereas linseed failed to establish.

Water balance

The field water balance of the College of Agriculture micro-watershed was computed for 2000 and 2001 rainy season considering all components. In 2000 and 2001, soil moisture at sowing was 340 and 201 mm, and at harvest was 237 and 275 mm, and rainfall was 231 and 375 mm, respectively. The runoff was negligible in both the years. The water use by the soybean crop grown on flat and BBF systems was 333 mm in 2000 and 283 mm in 2001 with no appreciable difference between them. The water use efficiency for soybean under different cropping systems was 1.81–2.2 kg mm^{-1} ha^{-1} for sole crop in 2000, and 5.25–5.51 kg mm^{-1} ha^{-1} for intercrop to 5.70–7.37 kg mm^{-1} ha^{-1} for sole crop in 2001 regardless of land treatments.

Lessons Learned from On-farm and On-station Strategic Research Work and Way Forward

As is apparent from the production statistics of Madhya Pradesh, soybean yield has doubled during the past 11 years; area has increased four times and total production five times. The increase in area under the crop has occurred partly through reduction in rainy season fallows, and partly by substitution of crops such as sorghum. While a sizable area under rainy season fallows still exists in the state (Vadivelu et al. 2001), the scope of increasing productivity exists only through increased crop yields and cropping intensity in the postrainy season. Using soil and water conservation measures and appropriate crop and nutrient management practice in Ringnodia micro-watershed, yields as high as 2 t ha^{-1} can be realized with ease in a normal rainfall year.

The Ringnodia micro-watershed presented an opportunity to explore the possibility of increasing crop yields as well as cropping intensity through farmers' participation, which was low to begin with and the soil and water resources in the village were poorly managed. It was possible to increase the water storage potential up to 70% of the total runoff potential. Also, the potential for soil erosion and waterlogging was substantially reduced. Farmers had good insight about the problems, but lacked initiative and resources to undertake massive development works. Their cooperation, catalyzed by our intervention, made a difference to the village resources in several ways as mentioned earlier.

Farmers were eager to construct more water storage structures as they have now realized the value of water storage without which their crops would suffer, wells would go dry, and even drinking water would become scarce. The open and tube wells could provide better insurance against drought provided the ground recharge could be enhanced. Farmers were interested in finding an alternative to soybean as prices have been low over the years.

Tractor mounted seed drill designed to sow on BBF was not found to be suitable for soybean as it had poor depth control, but was found to be appropriate for chickpea sowing as it could sow deep in the moist zone. Trees provide insurance against aberrant weather. Plantation efforts did not progress due to limited rainfall. However, custard apple and *jamun* had good survival ability. As some common land was available in the village there may be scope to develop these trees as a common property resource.

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