Productivity and Resource Use Management of Soybean-based Systems in a Vertic Inceptisol Watershed

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Abstract

Erratic rainfall and land degradation are the major constraints affecting productivity of soybean-based systems in central India. Operational scale watershed experiments were conducted for six seasons on a Vertic Inceptisol at ICRISAT, Patancheru, India to study the effects of improved management on land degradation, rainfall use efficiency, and the productivity of the soybean-chickpea sequential and soybean/pigeonpea intercropping systems. Improved management comprised of integrated nutrient management (additions of crop residues and Gliricidia *loppings) and sowing on broadbed-and-furrow (BBF) system. The traditional management consisted of sowing on flat landform and no addition of external sources of nutrients, except P application. These treatments were imposed on medium-deep and shallow phases of the soil type. The BBF system decreased surface runoff (16% of rainfall) compared to the flat system (21% of rainfall) with concomitant increase in deep drainage. Mean rainfall use efficiency was 70 to 73% across cropping systems and soil depths. Integrated nutrient management resulted in balanced soil N budget, whereas the traditional system showed a deficit of about 50 kg ha^{-1}. Denitrification and leaching losses were negligible. Landform treatments did not increase the crop yields significantly. Total productivity of the soybean-chickpea system ranged from 2.3 to 2.7 t ha^{-1} of seed yield and that of soybean/pigeonpea intercropping system ranged from 2.1 to 2.3 t ha^{-1} over the years, still showing a yield gap of about 1 t ha^{-1} for the Patancheru site. Simulated yield gap analysis for other nine sites in central India showed a mean yield gap of 1.2 to 1.9 t ha^{-1} under rainfed conditions, which could be even more in good rainfall years. This study has shown the potential of the improved technology for higher productivity and efficient use of natural resources on a Vertic Inceptisol, which has potential applications in the target region of central India.*

Soybean is grown on about 6 million ha in India mainly in the states of Madhya Pradesh, Maharashtra, and Rajasthan (FAO 2002). It is also grown in the states of Uttar Pradesh, Andhra Pradesh, Karnataka, and Tamil Nadu (Fig. 1). Despite the increase in production and area under soybean in the country, its productivity has stagnated at less than 1.0 t ha^{-1} (Fig. 2). Major increase in the area under soybean has occurred in Madhya Pradesh, where the annual rainfall spatially ranges from 800 to 1200 mm. The soils are Vertisols and associated Vertic Inceptisols. Major constraints to the production of soybean-based systems in Madhya Pradesh are physical, chemical, and biological forms of land degradation. Soil erosion is particularly high in central India because Vertisols and associated soils which predominate the landscape are prone to sheet and gully erosion under tropical monsoon climate. Therefore, to sustain crop yields of soybean-based systems, it is essential that land degradation is minimized, natural resources are efficiently used, and efficient cropping systems are introduced that will optimally use the natural resources. Considering these issues, a small watershed was developed on Vertic Inceptisol at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India with the following objectives:

- Evaluate the productivity of the selected soybean-based cropping systems with improved and traditional management on a Vertic Inceptisol.

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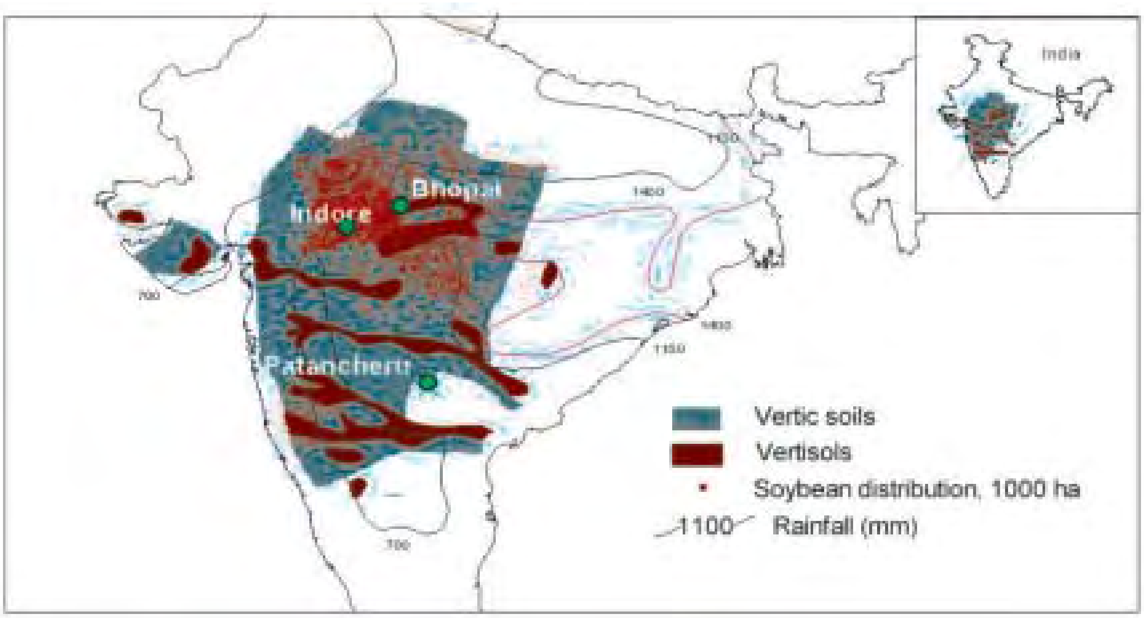

Figure 1. Soybean distribution and its agroecology in India.

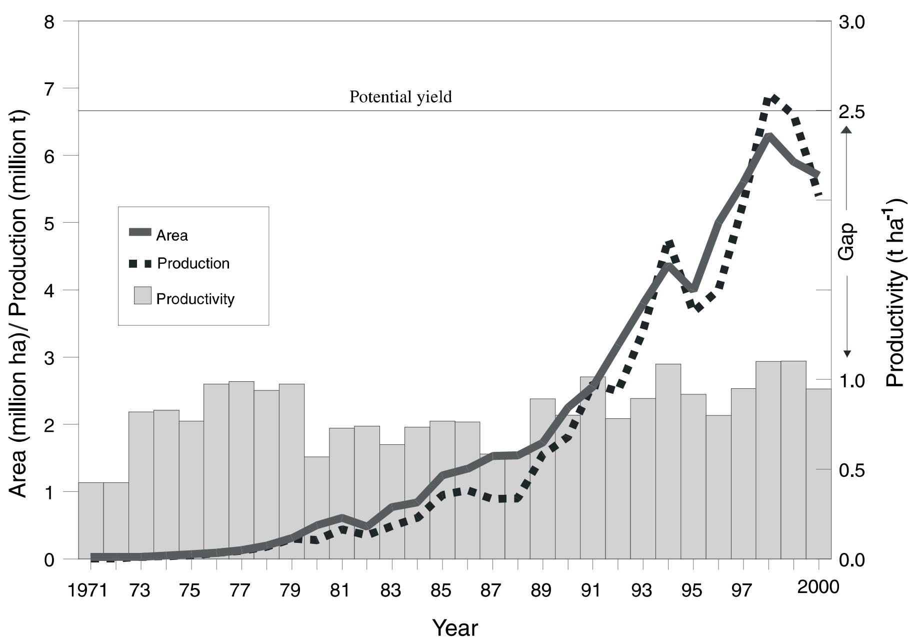

Figure 2. Area, production, and productivity of soybean in India.

- Evaluate the extent to which land degradation (soil erosion and nutrient depletion) can be minimized, productivity can be increased, and the other natural resources can be efficiently used with improved management.

Agroecology of the Patancheru Site and the Target Region

The annual rainfall (average of 30 years) of Patancheru is 800 mm. In the past 20 years, the rainfall was below normal in 8 out of 20 years. On an average 3 years out of 5 are average rainfall years (<25% variation of normal rainfall), 1 out of 5 years is above average (>25% of normal rainfall), and 1 out of 5 years are below average (<75% of normal rainfall). Since the average potential evapotranspiration required by any rainy season crop in Patancheru area is 600 mm, the below average years can be broadly termed as drought years. The coefficient of variability of the annual rainfall is 27% based on rainfall observed during the past 30 years.

The daily rainfall during the past seven years (1995–2001) clearly shows that at Patancheru the rainfall is unevenly spread during the rainy season (Fig. 3). It is not uncommon to receive 50% of the total seasonal rainfall in a few high volume, high intensity rainstorms. This amount of rainfall exceeds the water intake rate of most soils at Patancheru when the surface is fully wet. Rainfall then flows as surface runoff and causes extensive soil erosion and loss of nutrients. Effective rainfall is thus a fraction of the total rainfall received. This leads to reduced rainfall use efficiency caused by rainfall variability during the rainy season.

Madhya Pradesh receives annual rainfall varying from 800 to 1600 mm. Eighty percent of this is received from mid-June to mid-October. The rainfall increases from 800 mm in the western parts of Madhya Pradesh to 1500 mm in the eastern parts (Fig. 1). Madhya Pradesh has six soil types ranging from alluvial soils to deep black soils distributed over 12 agroclimatic zones. Medium to deep black soils receive 800 mm to 1200 mm annual rainfall. Because of poor manageability of black soils the cropping intensity is low (117%). Soybean-based cropping systems are mainly practiced. Various constraints of these soils are low infiltration rate, low organic matter content, poor structural stability, and vulnerability of soil to erosion. Harvesting and recycling of water on a watershed basis is required for sustaining production on these soils. Water balance of the two sites (Indore and Bhopal) in Madhya Pradesh is compared with that of Patancheru site (Fig. 4). The data shows that although the length of water availability period is longer at Patancheru compared to Indore and Bhopal, there are 3 months of rainfall exceeding potential evapotranspiration. Total rainfall in July and August received at Indore and Bhopal is greater than that received at Patancheru. This indicates that the opportunities for water harvesting are greater at these two sites in Madhya Pradesh compared to the Patancheru site. The problem of land degradation because of soil erosion is also greater at Indore and Bhopal. Therefore, it is expected that technological concepts developed at Patancheru site would have potential application at these two sites in Madhya Pradesh.

Current and Potential Land Use Systems in the Target Region

Various cropping systems are being followed in the target region of Madhya Pradesh where soybean crop has even greater potential in the region. Cropping systems practiced are cotton-wheat, maize-chickpea, pearl millet-wheat/mustard, pigeonpea-chickpea, rice-chickpea/mustard/wheat, sorghum-wheat, and soybean-wheat/chickpea. Madhya Pradesh accounts for more than 75% of total area and production of soybean in India. Soybean-wheat is a popular rotation in partially irrigated areas, while soybean-chickpea/safflower/lentil/linseed /mustard cropping systems are practiced in the rainfed areas. Soybean is also grown as an intercrop with medium-duration pigeonpea.

With improved management of black soils (Vertisols and Vertic Inceptisols), soybean is further expected to replace high input requiring crops such as cotton, maize, pearl millet, and sorghum grown during the rainy season. Soybean being a legume crop, the replacement of other crops by soybean is expected to result in saving of chemicals such as mineral fertilizers and biocides, thus contributing to the alleviation of environmental pollution.

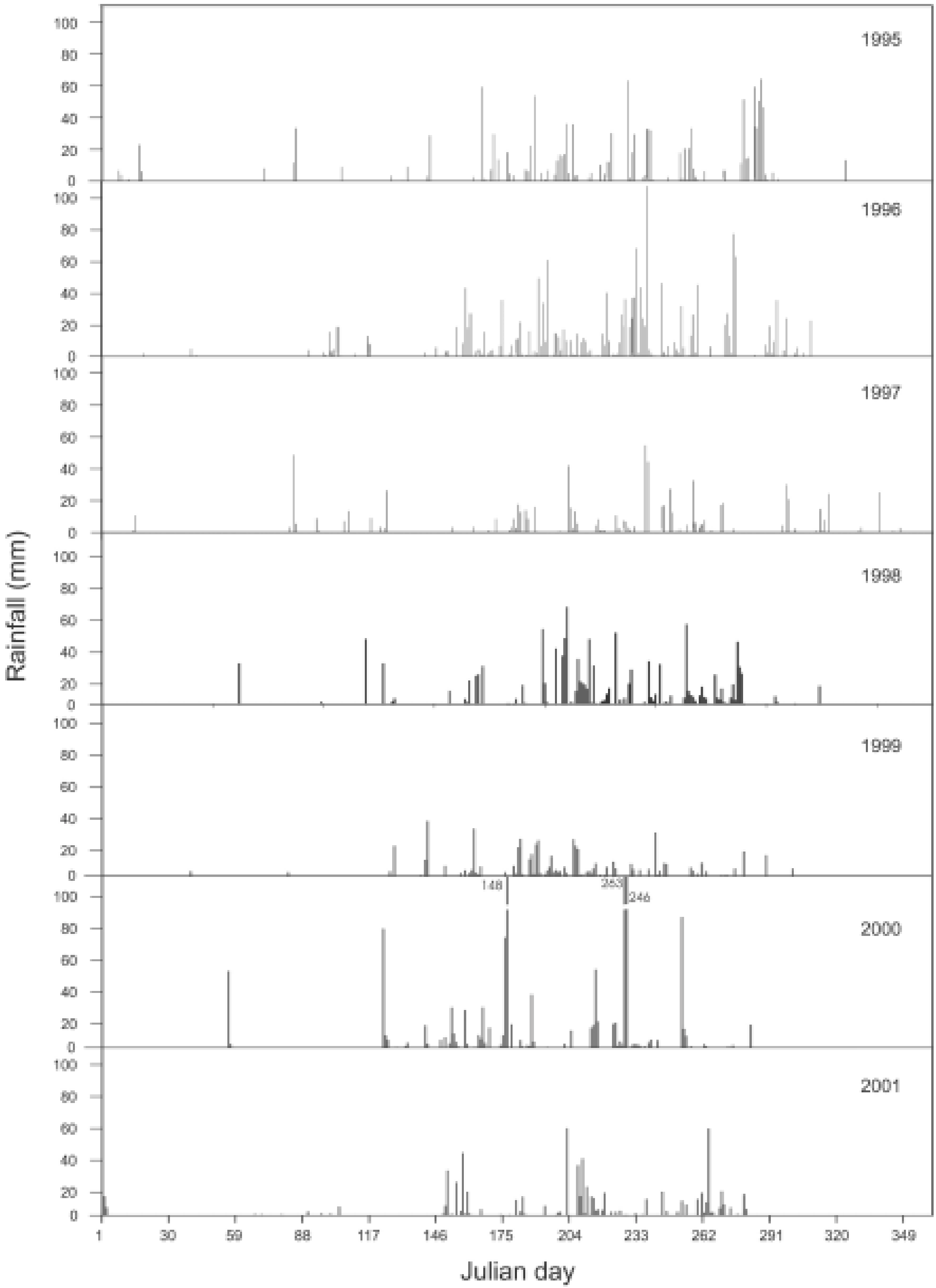

Figure 3. Daily rainfall at ICRISAT, Patancheru, India during 1995 to 2001.

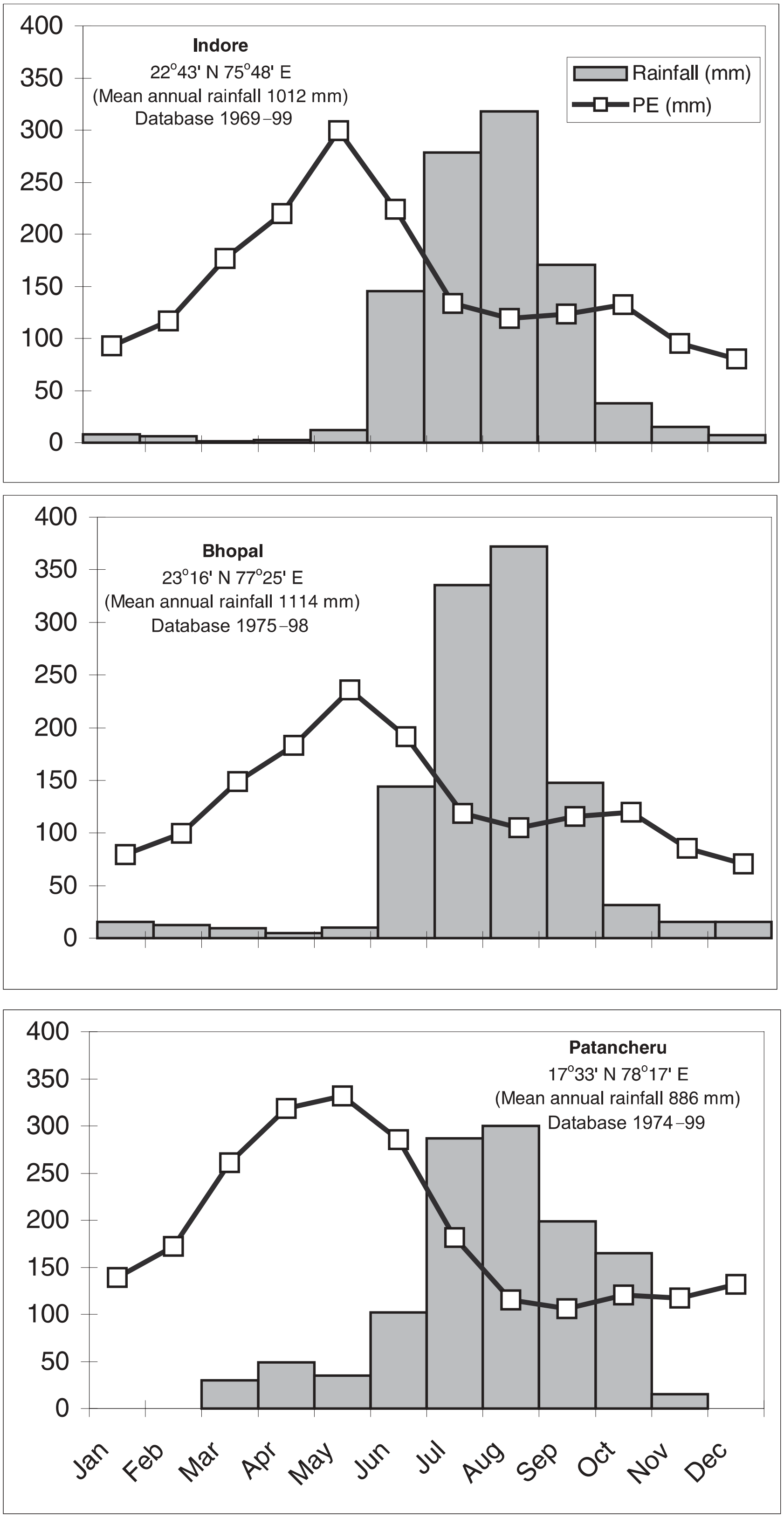

Figure 4. Water balance of Indore, Bhopal, and Patancheru sites.

Watershed Research at ICRISAT

The Patancheru site (BW7) serves as a reference site on a Vertic Inceptisol for strategic research on the soybean-based farming system (Fig. 5). Because the Vertic Inceptisols are relatively shallow in depth, the focus of the technology for these soils was to recharge the groundwater through land management and harvesting of excess rainfall in percolation tanks. Integrated nutrient management practices (legumes in the system, biofertilizers, and chemical fertilizers) was followed to meet the nutrient needs of the crops and to minimize the pollution of groundwater. Based on the toposequential soil depth the 15-ha watershed was divided into two hydrological units: medium-deep (50–90 cm) and shallow (<50 cm). These two hydrological units were further divided into two units on which two landform treatments were imposed: (1) broad-bed and furrow (BBF) with *Gliricidia sepium* on graded bands; and (2) flat landform with sowing on grade. Thus the watershed was divided into four hydrological units and on each unit two cropping systems were evaluated: (1) soybean/pigeonpea intercropping system; and (2) soybean-chickpea sequential cropping system except in the first year when only soybean-chickpea system was evaluated. This experiment has been conducted for six years from 1995/96 to 2000/01 and data have been collected on crop yields, runoff and soil erosion, water and nitrogen (N) balance, and groundwater recharging.

Surface runoff and soil erosion

Significant amount of runoff occurred in four out of six years of study (Table 1). Surface runoff, though variable over the years, averaged about 25% of the rainfall. Surface runoff was relatively more from the medium-deep soil than from the shallow soil. Because of greater time of concentration, total seasonal runoff and peak runoff rates were lower on the BBF landform compared to those on the flat landform on both the soil depths. On the medium-deep soil, BBF landform on an average reduced surface runoff by 22% compared to the flat landform, whereas on the shallow soil such reduction in runoff by the BBF system was about 18%. Whenever surface runoff occurred, the peak runoff rates were lower on the BBF landform than on the flat landform and did not differ significantly between the two soil depths (Table 1). Soil erosion observed between the landform treatments over the seasons was proportional to the amount of runoff observed and the peak runoff rates. Total soil loss averaged over the years was 2.4 to 2.5 t ha^{-1} on the BBF and 4.0 to 4.5 t ha^{-1} on the flat landform. Maximum soil loss was recorded during 2000/01 season, which was 6.5 to 6.7 t ha^{-1} on BBF and 11.1 to 12.0 t ha^{-1} on flat landform on two soil depths.

Simulated water balance of the soybean-chickpea sequential system

Water balance of the soybean-chickpea sequential system was simulated using Decision Support System for Agrotechnology Transfer (DSSAT) model (Tsuji et al. 1994). Model parameters for soil water balance were calibrated using the observed surface runoff and soil water dynamics data. Though the simulated runoff varied across seasons and soil depths, it averaged 160 mm for BBF medium-deep, 157 mm for BBF shallow, 213 mm for flat medium-deep, and 196 mm for BBF shallow (Table 2). On an average surface runoff constituted 16% of seasonal rainfall for the BBF landform and 20% of seasonal rainfall for the flat landform. This resulted in concomitant increase in deep drainage in both the soil types. For the medium-deep soil, average deep drainage for the cropping period was 135 mm for BBF (14% of rainfall) and 93 mm for the flat landform (11% of rainfall) (Table 2). For the shallow soil, average deep drainage was 183 mm for the BBF landform (21% of rainfall) and 139 mm for the flat landform (16% of rainfall). Total water use by the soybean-chickpea sequential system averaged over the seasons ranged from 481 to 515 mm across soil types and landforms (70 to 73% of rainfall) (Table 2).

Simulated water balance of the soybean/pigeonpea intercropping system

Water balance of the soybean/pigeonpea intercropping system was simulated using the Agricultural Production Systems Simulator (APSIM) (McCown et al. 1996) following the same approach as for the soybean-chickpea sequential system. As the intercropping system is of longer duration than the sequential system the values of various water balance

Table 1. Seasonal runoff, peak runoff rates, and soil loss in BW7 watershed at ICRISAT, Patancheru, India.

Year	Rainfall (mm)	Surface runoff (mm)		Peak runoff rate ($m^3 s^{-1} ha^{-1}$)		Soil loss ($t ha^{-1}$)	
		BBF[1]	Flat	BBF	Flat	BBF	Flat
Medium-deep							
1995/96	657	168	196	0.068	0.098	NR[2]	NR
1996/97	961	232	263	0.120	0.137	3.2	4.9
1997/98	546	1	3	0.003	0.003	0	0
1998/99	1043	200	290	0.135	0.145	2.7	5.5
1999/2000	401	0	0	0	0	0	0
2000/01	1062	477	641	0.270	0.385	6.5	12.0
Mean	778	180	232	0.099	0.128	2.5	4.5
Shallow							
1996/97	961	130	194	0.109	0.235	1.8	3.7
1997/98	546	2	2	0.003	0.004	0	0
1998/99	1043	251	283	0.130	0.168	3.4	5.3
1999/2000	401	0	0	0	0	0	0
2000/01	1062	489	588	0.270	0.320	6.7	11.1
Mean	803	174	213	0.102	0.145	2.4	4.0

1. BBF = Broad-bed and furrow.
2. NR = Not recorded.

Figure 5. BW7 watershed at ICRISAT, Patancheru, India.

Table 2. Simulated water balance components of soybean-chickpea sequential system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

Year	Rainfall[1] (mm)	Surface runoff (mm)		Deep drainage (mm)		Crop water use (mm)	
		BBF[2]	Flat	BBF	Flat	BBF	Flat
Medium-deep soil							
1995/96	653	81 (12)[3]	92 (14)	133 (20)	137 (21)	517 (79)	512 (78)
1996/97	973	231 (24)	272 (28)	165 (17)	172 (18)	559 (57)	563 (58)
1997/98	532	1 (0)	3 (1)	0 (0)	1 (0)	563 (100)	565 (100)
1998/99	876	171 (20)	259 (30)	215 (25)	126 (14)	518 (59)	510 (58)
1999/2000	401	8 (2)	18 (5)	0 (0)	0 (0)	395 (98)	406 (100)
2000/01	1251	466 (37)	630 (50)	295 (24)	121 (10)	541 (43)	499 (40)
Mean	781	160 (16)	213 (21)	135 (14)	93 (11)	515 (73)	509 (73)
Shallow soil							
1995/96	653	77 (12)	85 (13)	234 (36)	215 (33)	487 (75)	481 (74)
1996/97	973	142 (15)	207 (21)	327 (34)	271 (28)	496 (51)	503 (52)
1997/98	532	2 (0)	4 (1)	38 (7)	19 (4)	565 (100)	558 (100)
1998/99	876	228 (26)	269 (31)	206 (24)	152 (17)	487 (56)	487 (56)
1999/2000	401	16 (4)	40 (10)	0 (0)	0 (0)	400 (100)	388 (97)
2000/01	1251	479 (38)	574 (46)	296 (24)	177 (14)	459 (37)	472 (38)
Mean	781	157 (16)	196 (20)	183 (21)	139 (16)	482 (70)	481 (70)

1. During the cropping season.
2. BBF = Broad-bed and furrow.
3. Values expressed as percentages of rainfall are given in parentheses.

components (runoff, deep drainage, and water use) were generally larger than those for the sequential system (Table 3). However, when these water balance components were expressed as percentage of seasonal rainfall, their values were similar to those simulated for the soybean-chickpea sequential system.

Groundwater recharge

Overall improvement in land management in BW7 watershed resulted in increased groundwater recharge. Surface runoff and deep drainage water was captured in surface tanks and dug wells in the watershed. During 1996, 1998, and 2000 there was significant rise in water level (5 to 6 m) in the wells situated at the lower part of the watershed (Fig. 6). Because of low rainfall during 1999 the rise in water level in the wells was small. This additional water availability in the wells helped provide supplemental irrigation to the horticultural crops in the lower part of the watershed. Thus the overall rainfall use efficiency on watershed basis was greater than 50% in most years.

Measured nitrogen balance

Integrated nutrient management followed in the improved system (sowing on BBF + *Gliricidia* on bunds + addition of compost) resulted in balanced N budget for the soybean-chickpea sequential and soybean/pigeonpea intercropping systems (Table 4). In spite of N contributions through rainfall, biological nitrogen fixation (BNF), leaf fall, and roots, there was a net loss of about 50 kg N ha^{-1} for both the cropping systems in the conventional system (flat landform treatment) during the first four years. In the improved system, the application of *Gliricidia* loppings and compost provided about 45 kg N ha^{-1} without affecting the yield of crops in the nearby rows, thus balancing the N budget. Pigeonpea derived up to 89%, soybean up to 75%, and chickpea up to 42% of their N requirement through BNF.

Simulated nitrogen balance

Simulated N uptake and N fixation by the soybean/ pigeonpea intercropping system was variable across

Table 3. Simulated water balance components of soybean/pigeonpea intercropping system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

Year	Rainfall[1] (mm)	Surface runoff (mm) BBF[2]	Surface runoff (mm) Flat	Deep drainage (mm) BBF	Deep drainage (mm) Flat	Crop water use (mm) BBF	Crop water use (mm) Flat
Medium-deep soil							
1996/97	966	234 (24)[3]	268 (28)	184 (19)	198 (20)	545 (56)	534 (55)
1997/98	531	1 (0)	0 (0)	0 (0)	0 (0)	544 (100)	538 (100)
1998/99	1035	229 (22)	304 (29)	262 (25)	223 (21)	577 (56)	568 (55)
1999/2000	436	1 (0)	1 (0)	0 (0)	0 (0)	460 (100)	465 (100)
2000/01	1248	473 (38)	622 (50)	251 (20)	97 (8)	579 (46)	567 (45)
Mean	843	187 (17)	239 (21)	139 (13)	104 (10)	541 (72)	534 (71)
Shallow soil							
1996/97	966	137 (14)	207 (21)	360 (37)	299 (31)	521 (54)	514 (53)
1997/98	531	0 (0)	0 (0)	23 (4)	16 (3)	543 (100)	536 (100)
1998/99	1035	291 (28)	291 (28)	267 (26)	257 (25)	574 (55)	565 (55)
1999/2000	436	0 (0)	0 (0)	0 (0)	0 (0)	468 (100)	460 (100)
2000/01	1248	478 (38)	583 (47)	269 (21)	162 (13)	545 (44)	537 (43)
Mean	843	181 (16)	216 (19)	184 (18)	147 (14)	530 (71)	522 (70)

1. During the cropping season.
2. BBF = Broad-bed and furrow.
3. Values expressed as percentages of rainfall are given in parentheses.

seasons depending upon weather and amount of total dry matter produced by the system (Table 5). The N uptake by the intercropping system approximately ranged from 240 to 270 kg ha^{-1}, whereas N fixation approximately ranged from 170 to 250 kg ha^{-1}. There was no significant difference between the two landforms and the two soil depths for plant N uptake and N fixation by the soybean/pigeonpea intercropping system. Although denitrification and leaching of N were greater in the BBF treatment in both the soil depths because of higher rainfall infiltration and deep drainage, these constituted insignificant amounts of N losses from the soil to be of any environmental concern (Table 5).

Table 4. Nitrogen (N) contributions and balance (kg ha^{-1}) of soybean-based cropping systems in a Vertic Inceptisol watershed, ICRISAT, Patancheru, India, 1995–98[1].

Description	Soybean-chickpea BBF	Soybean-chickpea Flat	Soybean/pigeonpea BBF	Soybean/pigeonpea Flat
Total N uptake	197	198	220	214
Total N loss (runoff + deep drainage)	13	17	14	17
N additions (rainfall, fallen leaves, roots, and BNF)	165	168	200	183
N additions (compost, *Gliricidia* loppings)	45	0	44	0
N balance	0	–47	+10	–49

1. BBF = Broad-bed and furrow; BNF = Biological nitrogen fixation.

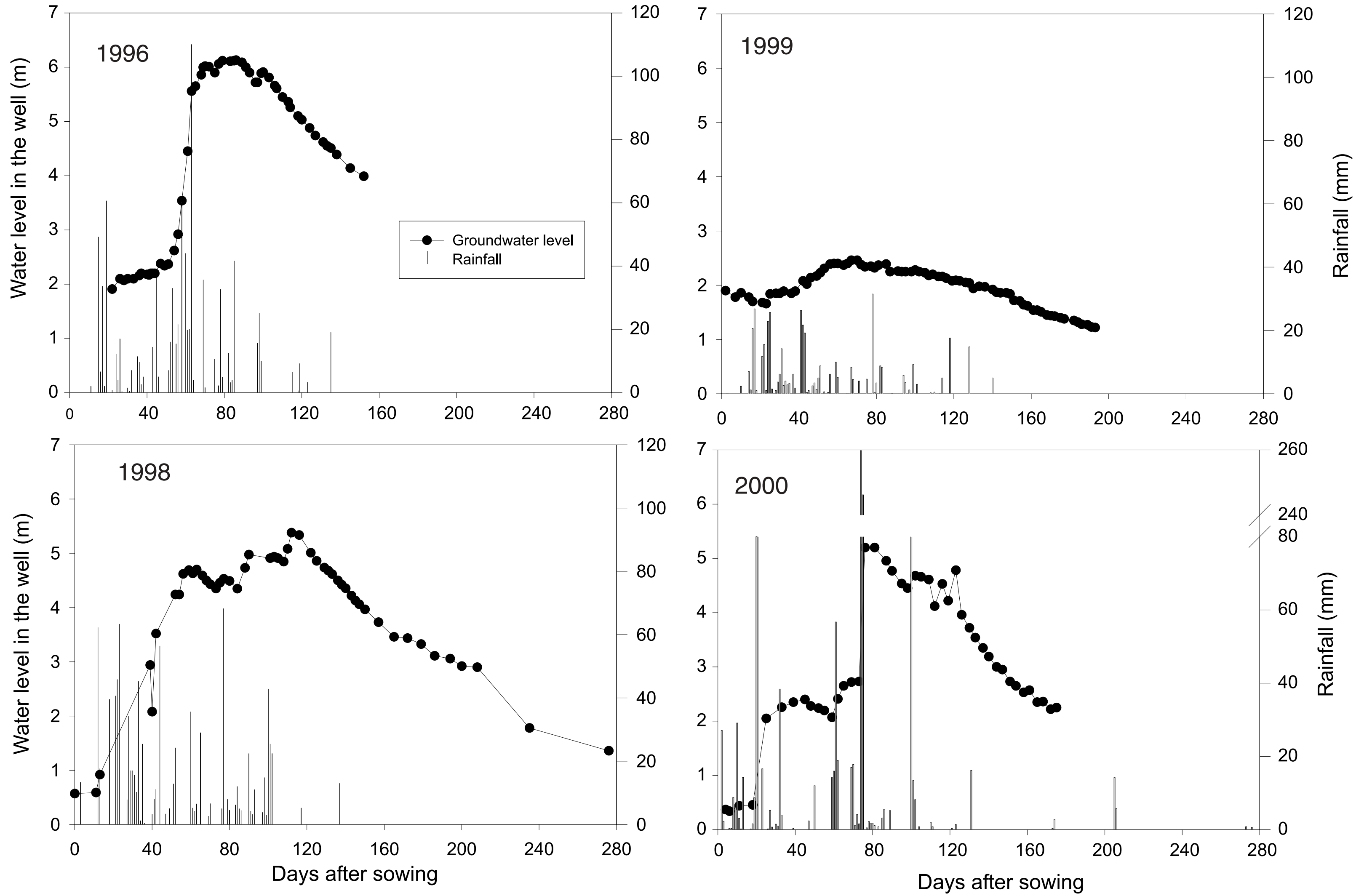

Figure 6. Rainfall distribution and groundwater level in the well in BW7 watershed.

Table 5. Simulated nitrogen (N) balance (kg ha^{-1}) of soybean/pigeonpea intercropping system on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Plant N uptake		N fixation		Denitrification		Leaching	
Year	BBF[1]	Flat	BBF	Flat	BBF	Flat	BBF	Flat
Medium deep soil								
1996/97	259	263	189	200	0.95	0.56	3.03	0.014
1997/98	242	239	169	168	0.60	0.72	0	0
1998/99	270	269	218	228	0.33	0.20	0.001	0
1999/2000	263	259	201	209	0.62	0.47	0	0
2000/01	271	269	253	251	0.024	0.023	0	0
Mean	261	260	206	211	0.50	0.39	0.61	0.002
Shallow soil								
1996/97	259	262	200	212	0.3	0.08	2.1	0.02
1997/98	242	239	174	175	0.14	0.10	0.001	0
1998/99	270	268	218	230	0.047	0.015	0.006	0.002
1999/2000	271	269	222	220	0.072	0.077	0	0
2000/01	265	262	231	244	0.03	0.002	0.005	0
Mean	261	260	209	216	0.12	0.05	0.42	0.004

1. BBF = Broad-bed and furrow.

Crop yields

The landform treatments did not significantly affect the yields of the component crops of the two cropping systems (Tables 6 and **7**). Soil depth did not influence the yield of rainy season crops in most years, except in low rainfall years the yields were higher on medium-deep soil. Major effect of soil depth was on the productivity of chickpea crop, which established and grew on the receding soil moisture. Chickpea yields were generally higher on medium-deep soil than on shallow soil. Pigeonpea yields were not significantly affected by soil depth. Across years and landforms, sole soybean yields ranged from 0.9 to 2.4 t ha^{-1} on medium-deep soil and 1.0 to 2.3 t ha^{-1} on shallow soil (Table 8). Chickpea yields ranged from 0.5 to 1.5 t ha^{-1} on medium-deep soil and 0.4 to 1.0 t ha^{-1} on shallow soil. Total productivity of the soybean-chickpea sequential system ranged from 1.9 to 3.7 t ha^{-1} on medium-deep soil and 1.5 to 3.3 t ha^{-1} on shallow soil. Average productivity of the soybean-chickpea system on medium-deep soil was 2.7 t ha^{-1} and on shallow soil it was 2.3 t ha^{-1}.

As expected, soybean yield in the intercropping system was less than that observed in the sole system. Across seasons, soil types, and landforms the intercropped soybean yield ranged from 0.7 to 2.0 t ha^{-1} and was slightly higher on medium-deep soil than on shallow soil (Table 7). Pigeonpea yield across seasons, soil types, and landforms ranged from 0.5 to 1.4 t ha^{-1}, giving an average yield of 0.9 t ha^{-1} irrespective of the soil type and landform. Total productivity of the soybean/pigeonpea intercropping system ranged from 1.2 to 2.9 t ha^{-1} across soil types and seasons, giving an average productivity of about 2.1 to 2.3 t ha^{-1} on shallow and medium-deep soils, respectively (Table 7). In the drought year of 1999/2000 the total productivity of the soybean/pigeonpea system was greater than that of the soybean-chickpea system when only about 400 mm of seasonal rainfall was received.

Long-term simulation of water balance and crop yields

Long-term analysis using simulation models and crop weather data of 26 years (1974–2000) have shown that in 70% of years total seasonal runoff ranged from 35 to 269 mm for shallow soil and 70 to 320 mm for medium-deep soil (Table 8). Deep drainage beyond the rooting zone ranged from 60 to 390 mm for shallow soil and 10 to 280 mm for medium-deep soil.

Table 6. Seed yield ($t\ ha^{-1}$) of soybean-chickpea sequential system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Soybean			Chickpea			Soybean and chickpea		
Year	BBF[1]	Flat	SE[2]	BBF	Flat	SE	BBF	Flat	SE
Medium-deep soil									
1995/96	1.7	1.9	0.06	0.5	0.6	0.02	2.2	2.5	0.05
1996/97	2.1	2.4	0.07	1.5	1.4	0.13	3.6	3.7	0.17
1997/98	1.0	0.9	0.06	1.5	1.1	0.12	2.5	2.0	0.11
1998/99	1.6	1.6	0.10	1.5	1.3	0.12	3.1	2.9	0.20
1999/2000	1.8	1.7	0.06	0.1	0.2	0.04	2.0	1.9	0.11
2000/01	2.4	2.1	0.12	0.9	0.7	0.08	3.3	2.8	0.18
Mean	1.8	1.8	-	1.0	0.9	-	2.8	2.6	-
Shallow soil									
1995/96	1.6	1.5	0.06	0.4	0.4	0.05	2.0	1.9	0.12
1996/97	2.3	2.3	0.07	1.0	1.0	0.13	3.3	3.3	0.17
1997/98	1.1	1.0	0.06	1.0	1.0	0.12	2.1	2.0	0.11
1998/99	1.5	1.7	0.10	1.0	0.8	0.12	2.5	2.6	0.20
1999/2000	1.7	1.5	0.06	0.1	0.1	0.04	1.8	1.5	0.11
2000/01	1.7	1.8	0.12	0.5	0.4	0.08	2.1	2.2	0.18
Mean	1.7	1.6	-	0.7	0.6	-	2.3	2.3	-

1. BBF = Broad-bed and furrow.
2. SE = Standard error (±).

Table 7. Seed yield ($t\ ha^{-1}$) of soybean/pigeonpea intercropping system in various treatments on a Vertic Inceptisol, ICRISAT, Patancheru, India.

	Soybean			Chickpea			Soybean and chickpea		
Year	BBF[1]	Flat	SE[2]	BBF	Flat	SE	BBF	Flat	SE
Medium-deep soil									
1996/97	1.5	1.8	0.07	0.9	1.1	0.16	2.4	2.9	0.17
1997/98	0.7	0.7	0.06	0.5	0.6	0.06	1.2	1.3	0.11
1998/99	1.1	1.1	0.10	1.4	1.2	0.12	2.4	2.4	0.20
1999/2000	1.4	1.5	0.06	0.8	0.8	0.08	2.2	2.3	0.11
2000/01	2.0	1.8	0.12	0.9	0.8	0.05	2.9	2.6	0.18
Mean	1.34	1.38	-	0.90	0.9	-	2.22	2.30	-
Shallow soil									
1996/97	1.5	1.7	0.07	0.9	1.0	0.16	2.4	2.7	0.17
1997/98	0.8	0.7	0.06	0.7	0.6	0.06	1.5	1.3	0.11
1998/99	1.0	0.9	0.10	1.4	1.1	0.12	2.4	2.1	0.20
1999/2000	1.5	1.3	0.06	0.7	0.6	0.08	2.2	1.9	0.11
2000/01	1.6	1.6	0.12	0.9	0.7	0.05	2.5	2.4	0.18
Mean	1.28	1.24	-	0.92	0.8	-	2.20	2.08	-

1. BBF = Broad-bed and furrow.
2. SE = Standard error (±).

Table 8. Simulated surface runoff and deep drainage, using weather data of 26 years (1974 to 2000) for shallow and medium-deep Vertic Inceptisols at ICRISAT, Patancheru, India.

Landform	Shallow soil	Medium-deep soil
Runoff in 70% of years (mm)		
Flat	60–269	80–320
Broad-bed and furrow (BBF)	35–190	70–280
Deep drainage in 70% of years (mm)		
Flat	60–330	10–245
Broad-bed and furrow (BBF)	80–390	25–280

Total productivity of the soybean-chickpea sequential system was 3 to 4.1 t ha^{-1} on shallow soil and 3.5 to 4.7 t ha^{-1} on medium-deep soil in 70% of years (Table 9). Total productivity of the soybean/pigeonpea intercropping system was 2.9 to 4.2 t ha^{-1} on shallow soil and 3.1 to 4.3 t ha^{-1} on medium-deep soil. These results show the potential of the environment and technology for achieving higher yields provided the natural resources are managed properly. Comparing the potential yields with observed yields of the two cropping systems obtained in the BW7 watershed, it becomes evident that in spite of high yields obtained in the watershed a yield gap of at least 1.0 t ha^{-1} still exists.

Potential productivity and yield gap of soybean growing locations

To assess the scope for increasing productivity of soybean in the major soybean-growing region of India, potential productivity and yield gaps were assessed using the CROPGRO-soybean simulation model. Based on the yield gaps the locations or the regions could be targeted to bridge the yield gap. This analysis was performed for 10 locations in India for which the soils and historical weather records were available. These locations are Raisen, Betul, Guna, Bhopal, Indore, Kota, Wardha, Jabalpur, Amaravati, and Belgaum (Table 10). The potential yields (water limited) varied from year to year because of weather variability. There were large differences in maximum and minimum obtainable yields for a location. Mean yield obtained for a location was compared with the mean observed yield of the last five years to calculate the yield gap. Simulated mean yield for Raisen and Wardha was greater than 2500 kg ha^{-1}, while for Betul, Jabalpur, Bhopal, and Indore it ranged from 2000 to 2500 kg ha^{-1}. For other locations the simulated mean yield ranged from 1200 to 2000 kg ha^{-1}. The yield gap for various locations ranged from 235 to 1955 kg ha^{-1}. The yield gap was minimal for Kota where sufficient area is under irrigation. For Raisen, Betul, Bhopal,

Table 9. Simulated yield potential (t ha^{-1}) of soybean-chickpea sequential and soybean/pigeonpea intercropping systems for shallow and medium-deep Vertic Inceptisols at ICRISAT, Patancheru, India[1].

Crop	Shallow soil	Medium-deep soil
Soybean-chickpea system		
Soybean	2.2–3.0	2.2–3.0
Chickpea	0.5–1.5	0.8–1.9
Soybean and chickpea	3.0–4.1	3.5–4.7
Soybean/pigeonpea system		
Soybean	1.8–2.1	1.9–2.1
Pigeonpea	1.0–2.3	1.2–2.3
Soybean and pigeonpea	2.9–4.2	3.1–4.3

1. In 70% of years using weather data of 26 years (1974 to 2000).

Table 10. Simulated soybean yields and yield gap for the selected locations in India.

Location	Mean sowing date	Mean harvest date	Simulated yields (kg ha^{-1})				Mean observed yield[2] (kg ha^{-1})	Yield gap (kg ha^{-1})
			Minimum	Maximum	Mean	SD[1]		
Raisen	22 Jun	11 Oct	393	4670	2882	1269	-	-
Betul	19 Jun	8 Oct	924	3296	2141	603	858	1283
Guna	30 Jun	14 Oct	342	2916	1633	907	840	793
Bhopal	16 Jun	8 Oct	805	3064	2310	615	1000	1310
Indore	22 Jun	10 Oct	760	4588	2273	939	1122	1151
Kota	3 Jul	16 Oct	0	3188	1165	936	1014	151
Wardha	17 Jun	6 Oct	1824	3955	3040	640	1042	1998
Jabalpur	23 Jun	11 Oct	1132	2477	2079	382	896	1183
Amaravati	18 Jun	8 Oct	440	2624	1552	713	942	610
Belgaum	17 Jun	30 Sep	858	2943	1844	629	570	1274

1. SD = Standard deviation.
2. Mean of reported yields of five years (1996/97 to 2000/01).

Indore, and Wardha, the mean yield gap ranged from 1183 to 1955 kg ha^{-1}. However, in some years greater yield gap is expected as indicated by the maximum obtainable yields. Based on the maximum obtainable yield, the yield gap ranged from 1812 to 2930 kg ha^{-1} for various locations. These results show that there is a considerable potential to bridge the yield gap between the actual and potential yield through adoption of improved resource management technologies.

Extension of BW7 Watershed Work

In BW7 watershed we have successfully shown that integrated watershed management technology has resulted in crop intensification of the soybean-based system as well as increased use of excess rainfall stored in surface ponds and dug wells. The BBF system decreases surface runoff and soil erosion thus reducing soil degradation. The target region of Madhya Pradesh has similar agroecology as the Patancheru watershed area, except that rainfall intensity and amounts in July and August are greater than those observed at Patancheru. This is expected to cause severe soil erosion and waterlogging at Bhopal and Indore watershed sites. Therefore, the BBF system of land surface management is expected to perform better in controlling runoff and soil erosion, and to alleviate waterlogging of heavy clay soils. Groundwater recharging at these two sites could be improved by constructing percolation tanks or gully plugging.

Future Work Plan

There is a need to continuously monitor the long-term soil, water, and nutrient management on sustainability and soil quality changes in the watershed, particularly sequestration of carbon. There is also a need to quantify the economic losses due to land degradation and examine how these losses can be minimized. As water availability in the watershed has been increased due to surface ponds and wells, there is a need to quantify the overall use efficiency including water use by the horticultural system. The digital terrain model developed at the Michigan State University, USA will be evaluated for this watershed. The work done at BW7 watershed will be scaled-up for extending the benefits of watershed management to rural communities. The national agricultural research system (NARS) scientists working in other watersheds will be trained in the instrumentation for data recording. This watershed shall continue to serve as a training ground for government officials working in the area of watershed management and the farmers in the region.

References

FAO (Food and Agriculture Organization of the United Nations). 2002. Website: http://www.fao.org

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., and **Freebairn, D.M.** 1996. APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. Agricultural Systems 50:255–271.

Tsuji, G.Y., Jones, J.W., and **Balas, S.** (eds.) 1994. DSSAT V3. Honolulu, Hawaii, USA: University of Hawaii.