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Sustainability of Soybean-based Cropping Systems on a Vertic Inceptisol: 1. Effects of Management on Runoff, Soil Erosion, Soil Fertility and Crop Yields

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ABSTRACT : Effects of improved versus traditional management of a Vertic Inceptisol on the productivity and resource use of two soybean-based cropping systems was studied from 1995 to 2003. Improved management comprised of sowing on broadbed-and-furrow landform and additions of nutrients through composted crop residues and prunings of Gliricidia (*Gliricidia sepium* (L.)); while traditional management consisted of sowing on flat landform and no addition of organic sources of nutrients. These management treatments were applied on both the shallow and medium-deep phases of an operational scale watershed. Cropping systems evaluated were soybean-chickpea sequential (SB-CP) and soybean/ pigeonpea intercrop (SB/PP) systems.

Improved management decreased surface runoff by 24 to 27% and soil loss by 44 to 47% on the two soils when compared with traditional management. Organic carbon (OC), total nitrogen and extractable phosphorus in the soil declined across all management treatments over the study period. Extractable micronutrients (Zn, S and B) in the soil were also deficient at the end of the study period. In spite of decrease in productivity of the cropping systems over the years, total grain yield productivity of the SB-CP system in the last three seasons was 21% higher on the medium-deep and 9% higher on the shallow soil with improved management compared to traditional management. Grain yield productivity of the SB/PP inter-crop system was marginally higher with improved management. It is concluded that, in addition to improved land and water management practices, significant improvements in soil fertility status of Vertic Inceptisols would be needed for balanced nutrition of crops for sustaining production on these soils.

Keywords: Crop residues, soil erosion, soil fertility decline, sustainability, semi-arid tropics.

Vertic Inceptisols occupy about 60 million hectare (M ha) in the states of Madhya Pradesh, Maharashtra and Andhra Pradesh in India (Sehgal and Lal, 1988). These soils occur in association with Vertisols in toposequence on slopes not exceeding 5%. Vertic Inceptisols have similar physical and chemical properties as the Vertisols, except that these are shallower (depth of black soil material), some-what lighter in texture and have low to medium available water-holding capacity (100-200 mm plant extractable water). Annual rainfall in Central India, where these soils predominate, varies from 750 to 1300 mm with almost 80% received from June until September (Singh, 1997). Total rainfall during these four months often exceeds the water requirement of crops grown during the rainy season. Because of their location in toposequence, major constraints for crop production on these soils are a high run-off of rainwater and associated soil erosion, depletion of nutrients and beneficial organisms leading to decline in crop productivity. Under such biophysical conditions farmers find soybean [*Glycine max* (L.) Merr.] as the most suitable crop in the region. Soybean as an oilseed crop has good economic value; the farmers are expanding soybean-based agriculture on both Vertisols and Vertic Inceptisols. Land area under soybean cultivation has increased exponentially from 0.03 M ha in 1969 to 6.22 M ha in 2001 and then declined to 5.68 M ha due to unusual drought (FAOSTAT, 2004). Despite the increase in area under the crop, its productivity has stagnated at less than 1.0 t ha^{-1}. Therefore, for sustainable increase in crop yields of soybean-based systems it is essential that suitable land management and agronomic practices are introduced so that land degradation is minimized and natural resources are efficiently used for crop production.

Over the last 20 years various land surface management practices (e.g. tillage, ridges-and-furrows, broadbed-and-furrows, etc.) for the Vertisols have been investigated in

India to regulate the flow of excess rainwater over land, thereby minimizing soil erosion and increasing infiltration. Between 1975-1980, Pathak *et al.* (1985) studied the influence of four land management systems on annual run-off and soil loss from the Vertisol watersheds at ICRISAT, Patancheru. In their study, the system of broadbed-and-furrows (BBF) with field bunds reduced the average annual run-off to one-third and soil loss to one-eleventh when compared to traditional flat landforms. In a subsequent study, Srivastava and Jangawad (1988) measured runoff and soil loss for 12 years on two small agricultural watersheds dominated by Vertisols. One of the watersheds had an improved management system that included BBF system as a landform treatment, double cropping and improved soil fertility management. The other watershed had a traditional management system characterized by fallow during the rainy season followed by a crop during the postrainy season on a flat land configuration with the application of some farmyard manure. The improved system lost only 13.7% of rainfall as run-off compared to 24.1% run-off in the traditional system. Soil loss in the improved system amounted to 1.46 t ha^{-1} $year^{-1}$ compared to 6.4 t ha^{-1} $year^{-1}$ in the traditional system. The impacts of these improved management systems on soil quality after 24 cropping cycles resulted in 7.4 t ha^{-1} more carbon in the soil profile as compared to the traditional management (Wani *et al.*, 2003). In a higher rainfall region of Central India, Gupta and Sharma (1994) observed the influence of four land configuration treatments on *in-situ* conservation of rainwater during 1988-1991 on a Vertisol. Improved landform treatment (raised-sunken beds), reduced run-off by 6% and soil loss by 42% compared to the traditional landform (flat beds) treatment.

The present study is focused on Vertic Inceptisols, where soil erosion induced degradation due to excessive rainfall limits the potential of the soybean-based cropping systems more severely than on Vertisols due to shallower soil profiles and lower water holding capacity. The objective of the study was to evaluate the long-term effects of improved vis-à-vis traditional management of a Vertic Inceptisol on the productivity of two soybean-based cropping systems, surface runoff and soil erosion and balance of organic carbon and other nutrients in the soil. The results of the nine-year field study are presented in this paper and the broader implications for sustainability of the production systems on Vertic Inceptisols are discussed.

Materials and Methods

Site, soils and the watershed experiment

This study was initiated in 1995 at the ICRISAT farm, Patancheru (17 32' latitude, 78 16' long and 540 m elev.), Andhra Pradesh, India on a Vertic Inceptisol, which according to the USDA is classified as a member of the fine, montmorillonitic, isohyperthermic family of paralithic Vertic Ustopepts (Vertic cambisol as per FAO classification). After many years of grassed-fallow, the land was cleared in summer of 1995 and a 15 ha watershed was designed and developed. General slope of the land was less than 2%. The topo-sequential depth survey showed variation in soil depth (depth of top black soil) from 0.30 to 0.90 m, underlain by a coarse weathered parent material (granite-gneiss complex pediment covered by basalt) locally known as "murrum". The depth of the soil decreased from east to west along the general slope of the land and only part of the watershed (4.6 ha) was used for the experiment (Fig. 1). The selected portion of the watershed was divided into two main hydrological units: medium-depth (50-90 cm) and shallow-depth (<50 cm). These hydrological units were further divided into two units each on which improved and traditional management treatments were imposed. Thus, the watershed in total had four hydrological units: medium-depth improved management (1.19 ha), medium-depth traditional management (1.29 ha), shallow-depth improved management (1.15 ha) and shallow-depth traditional management (0.96 ha) (Fig. 1).

Improved management comprised of sowing on broadbed-and-furrow (BBF) landform with Gliricidia (*Gliricidia sepium* (L.)) grown on graded field bunds between plots, the prunings of which were added to the soil during the cropping season along with the additions of composted crop residues of soybean [*Glycine max* (L.) Merr.], chickpea [*Cicer arietinum* (L.)] and pigeonpea [*Cajanus cajan* (L.) Millsp.] at the start of the season. Traditional management comprised of flat landform with sowing along the graded field bunds. No organic matter was added to this treatment except the additions through natural leaf senescence and roots. Each hydrological unit was further partitioned into 6 to 8 plots on which cropping systems were randomly applied. The two cropping systems evaluated from 1996/97 to 2003/04 were soybean-chickpea sequential (SB-CP) and soybean/pigeonpea intercrop (SB/PP) systems, except during the first year (1995/96 season) when only SB-CP was grown in all the four hydrological units.

Field preparation and sowing of crops

To prepare the fields to BBF and flat landforms, every year the following procedure was followed. All the field operations were carried out from ridge to grassed waterway (Fig.1) and vice versa with a bullock-drawn machine named "tropicultor". Different tools were fixed on this tool carrier depending upon the operation to be carried out. First plowing (primary tillage) was done in the month of March just after the harvest of the postrainy season crop of the previous season. Plots laid to BBF system were plowed with a mould board plough and the plots laid to flat system with ridge tines. The depth of primary tillage was 0.15 to 0.20 m. Second cultivation was done in all the plots in the month of April with ridge tines to break soil clods. Third cultivation was done in the month of May with a cultivator to shape up the beds and furrows in the plots allocated to the BBF system and with a blade-harrow in the plots allocated to the flat system for smoothing the land surface. BBF system comprised of 1 m wide raised beds and 0.5 m wide furrows on either side of the bed. Fertilizer was applied along with sowing of crops just after the start of the season. In case of SB-CP sequential system, the plant population kept was 30 plants m^{-2} for soybean in the rainy season and 35 plants m^{-2} for chickpea in the postrainy season. For SB/PP intercrop system, plant population was 30 plants m^{-2} for soybean and 3.3 plants m^{-2} for pigeonpea. Soybean to pigeonpea row-ratio was 4:1 in the intercrop system. Four rows of soybean or chickpea, each 0.27 m apart, were sown on each raised bed. Row spacing between pigeonpea rows was 1.5 m, that is, only one row of pigeonpea was sown on each bed. Similar row arrangement for crops was followed in the traditional management plots (flat landform). Crop cultivars grown were cv. PK 470 of soybean (110 days duration), cv. ICCC 37 of chickpea (100 days duration) and ICPL 87119 (220 days duration). After sowing of crops the first inter-cultivation was done at 21 days after sowing (DAS) and one hand weeding at 25 DAS. Second inter-cultivation was done at 30 DAS only if the weather permitted.

Nutrient additions to management treatments

Each year both the improved and traditional management treatments received 18 kg P ha^{-1} as single superphosphate prior to sowing of the rainy season crop. Additionally, 23 kg N ha^{-1} as urea in 1998 and 34 kg K ha^{-1} as muriate of potash (KCl) in 1999 were applied to both the improved and traditional management treatments. Crop residues of soybean and chickpea produced each year were composted in soil pits dug outside the watershed and applied to the improved management treatment at the start of the following season. Total amount of composted residues thus applied to the improved management treatment during the nine years was 15.7 t ha^{-1}, which provided 2.73 tons carbon, 187.0 kg N, 21.4 kg P and 101.2 kg K ha^{-1}. Similarly Gliricidia prunings were added to the soil under improved management during both the rainy and postrainy seasons. This amounted to 8.6 t ha^{-1} of Gliricidia applied during the nine years to provide an additional 3.21 tons carbon, 212.8 kg N, 12.9 kg P and 160.3 kg K ha^{-1}. Thus, the total amounts of nutrients applied to improved management from various sources were 5.94 tons carbon, 443 kg N, 194 kg P and 295 kg K ha^{-1} and to the traditional management were 23 kg N, 160 kg P and 34 kg K ha^{-1}.

Pest management

Need based integrated pest management practices were followed in the whole watershed area to control the pests and diseases of the rainy and postrainy season crops. Control measures were taken after the pest populations or the disease severity reached a certain threshold level (Ranga Rao *et al.*, 2002). For example, the pest incidence varied from year to year on the pigeonpea and chickpea crops, which were attacked by the pod borer (*Helicoverpa* spp.). These infestations were controlled by spraying nuclear polyhedrosis virus (NPV) or chemical pesticides when the insect population exceeded the threshold levels (2 small larvae per plant for chickpea and 3 small larvae per plant for pigeonpea). Manual shaking of pigeonpea crop was also undertaken during the peak larval periods to dislodge the larvae from the plants for immediate relief to the crop.

Measurements of runoff and soil erosion

To measure surface runoff from each hydrological unit, H-flumes were installed at the lowest point of each hydrological unit (Fig. 1). The height of water passing

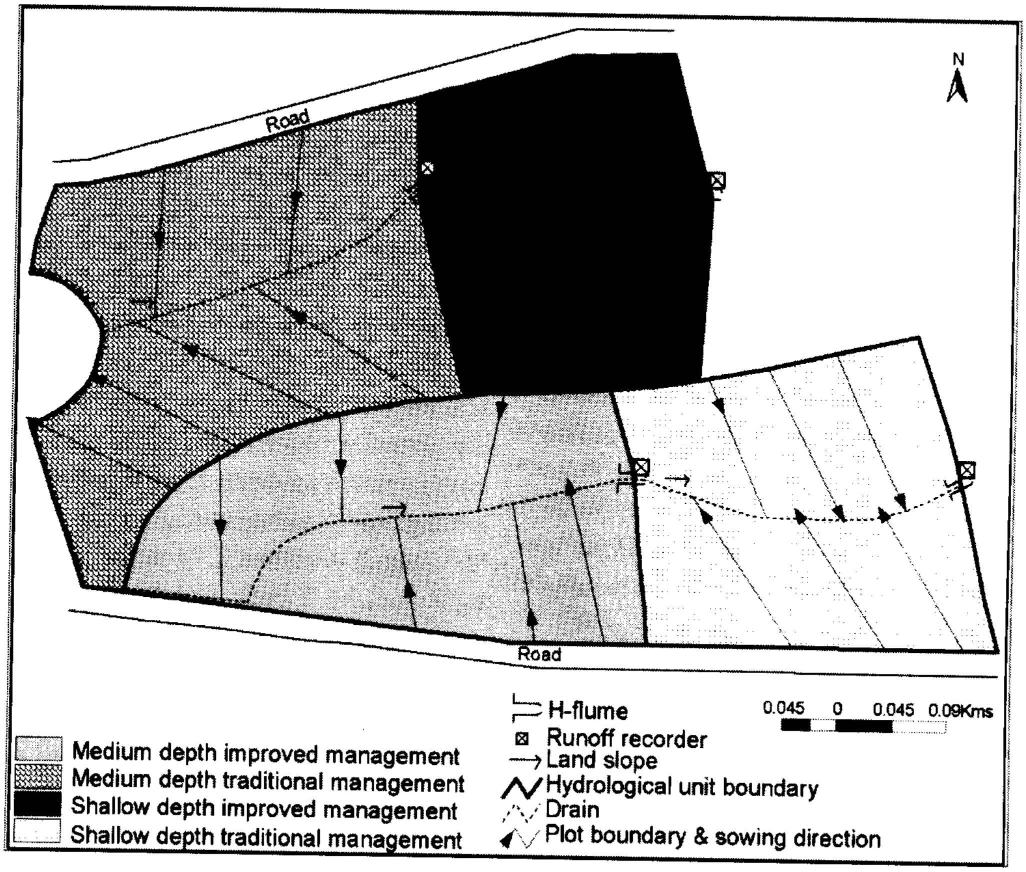

Fig. 1. Field layout of the BW 7 watershed showing four hydrological units, distribution of plots and location of runoff and soil loss measuring devices.

through a H-flume was continuously recorded with a digital runoff recorder (Thalimedes, OTT, Messtechnik GmbH & Co., KG, Germany*). Runoff associated with each rainfall event was summed to calculate cumulative runoff during the season. During a runoff event, samples were taken at five minutes intervals with an automatic sampler and later oven dried to estimate the sediment concentration in each sample. Soil loss during each runoff event was calculated as the product of sediment concentration and the amount of runoff during the sediment sampling interval and integrated over the whole runoff duration. Thus, the total soil loss during the season was the sum of sediment loss over all the runoff events during the season (Pathak *et al.*, 2004). H-flumes installed at the lowest point of hydrological units on shallow soil also recorded runoff draining out from the medium-deep soil via the common grassed waterways. Runoff and soil loss from the hydrological units on shallow soil was calculated as the difference between the observations obtained for shallow and medium-deep soil.

Soil moisture monitoring

To monitor changes in soil water content, three neutron probe access tubes were installed in each plot. These tubes were located on the diagonal transect of each plot to have representative sampling of soil water content. As the "murrum" underlying the black soil retains and supplies water to the root system, the depth of access tubes installed exceeded the depth of black soil to account for the maximum possible depth of rooting. Total number of access tubes installed in each hydrological unit was at least 18. Neutron probe (Model 4300, Troxler Electronic Lab., Raleigh, NC*) readings were taken at 7–10 days intervals in each access tube at 0.15 m increments from 0.3 m to 1.5 m depth. Probe readings were converted in to percent volumetric water content using neutron probe calibration curves developed separately for each hydrological unit. Water content of the top two soil layers (0–10 cm and 10–22.5 cm) near each neutron probe tube was determined gravimetrically at the time neutron probe observations.

*Mention of a product name does not constitute any endorsement by ICRISAT

Crop yields at maturity

Every year crop yields were determined from five subplots per plot, each measuring 225 m^2. The harvested material was oven dried at 60°C for 48 hours and then weighed to determine total biomass and grain yield.

Measurement of soil carbon and other nutrients

Soil samples were collected from each plot in June 1995 and again 2002 to study the impact of the different treatments on soil organic carbon. Samples were taken from five random positions per plot at 0-15, 15-30, 30-60 and 60-90 cm soil depths and pooled for each sampling depth per plot for further processing and analysis. Organic carbon content was determined using the dichromate digestion method (Nelson and Sommers 1996) and total nitrogen by the Kjeldahl method modified by Dalal *et al.,* (1984). Available zinc, sulfur, and boron were determined by the methods of Lindsay and Norvell (1978), Tabatabai (1996) and Keren (1996), respectively.

Statistical analysis

Genstat software version 7.0 (Payne, 2002) was used to analyze soil carbon and crop yield data of each year of each crop component of cropping systems and using analysis of variance (ANOVA) routine in REML (Restricted Maximum Likelihood Method). Pooled data of all years of each crop of the SB-CP and SB/PP systems were analyzed using repeated measurements in REML. Plots were taken as subjects and year as time point. Soil depth and management treatments were taken together as a factor product and used with year in the fixed model to do the analysis. Yields of the component crops were analyzed using 1995 to 2003 seasons data for the SB-CP system and 1996 to 2003 seasons data for the SB/PP intercropping system. Standard errors of difference were calculated to compare the management and cropping system treatments effects on crop yield and soil carbon attributes.

Results and Discussion

Rainfall, surface runoff and soil erosion

Mean annual rainfall for the site is 890 mm and about 76% of this (i.e., 680 mm) is received during the main rainy season, which extends from June (DOY 158-166) to September (DOY 273) (Fig. 2). Two crops are normally grown during the year, the first crop during the main rainy season and the second one during the postrainy season on stored water in the soil profile with occasional rainfall in some years. Most of the surface runoff due to rainfall occurs during the last week of July to end of September (DOY 207 – 278), which needs to be managed to control soil erosion and water harvesting in the surface ponds or groundwater recharging.

During the study period, four out of eight years received above normal (>680 mm) rainfall during the rainy season when significant amounts of runoff occurred (Table 1). Below 680 mm rainfall, runoff was negligible, with no runoff occurring at all in the 1999/2000 season. Unless rainfall occurs in intense storms, these results suggest that for regions of India where the seasonal rainfall (June to September) is less than 680 mm, soil erosion by water may not be a significant problem on Vertic Inceptisols. Improved management decreased surface runoff and soil loss from both the medium-deep and shallow soils. These differences in surface runoff and soil loss between the two treatments were consistently recorded whenever a runoff causing rainfall event occurred. On the medium-deep soil, total seasonal runoff averaged over eight years was 131 mm for improved management and 179 mm for the traditional management, indicating 27% reduction in runoff with improved management. On the shallow soil, such reduction in runoff with improved management was 24% over the traditional management. Soil erosion in the traditional management treatment when averaged over eight years was 3.6 t ha^{-1} for the medium-deep soil and 3.4 t ha^{-1} for the shallow soil; which decreased to 1.9 t ha^{-1} with improved management on both the soils. On an average, improved management decreased soil erosion by 44-47% compared to the traditional management on both the soils. In some years the soil erosion was as high as 11-12 t ha^{-1} for the traditional management. These results are in line with the results reported earlier by Srivastava and Jangawad (1988) for the Vertisols at ICRISAT, Patancheru, India, but the absolute values of soil erosion from the Vertic Inceptisol were less compared to the Vertisols, which averaged 6.4 t ha^{-1} $year^{-1}$ for the traditional management and 1.46 t ha^{-1} $year^{-1}$ for the improved management. In the present study for each cm of surface runoff, 0.168 t ha^{-1} of soil was lost from the Vertic Inceptisol across management treatments and soil depths (Fig. 3). A strong correlation between runoff and soil erosion (R^2 = 0.97) means that if surface runoff from a Vertic Inceptisol in known, then

Table 1. Seasonal rainfall, surface runoff and soil loss in the improved and traditional management treatments during the 1996/97 to 2003/04 cropping seasons.

Season	Rainfall (mm)	Surface runoff (mm)		Soil loss (t ha^{-1})	
		Improved	Traditional	Improved	Traditional
Medium depth					
1996/97	961	232	263	3.2	4.9
1997/98	546	1	3	0	0
1998/99	1043	200	290	2.7	5.5
1999/2000	401	0	0	0	0
2000/01	1062*	477	641	6.5	12
2001/02	629	12	23	0.02	0.13
2002/03	556	0	4	0	0
2003/04	808	127	209	2.9	6.4
Mean	751	131	179	1.9	3.6
Range	401-1062	0-477	0-641	0-6.5	0-12.0
Shallow depth					
1996/97	961	130	194	1.8	3.7
1997/98	546	2	2	0	0
1998/99	1043	251	283	3.4	5.3
1999/2000	401	0	0	0	0
2000/01	1062*	489	588	6.7	11.1
2001/02	629	14	46	0.03	0.36
2002/03	556	0.19	2.8	0	0
2003/04	808	123	215	2.3	6.7
Mean	751	126	166	1.9	3.4
Range	401-1062	0-489	0-588	0-6.7	0-11.1

* Heavy storms excluded because of flooding of the flumes. Total seasonal rainfall was 1249 mm.

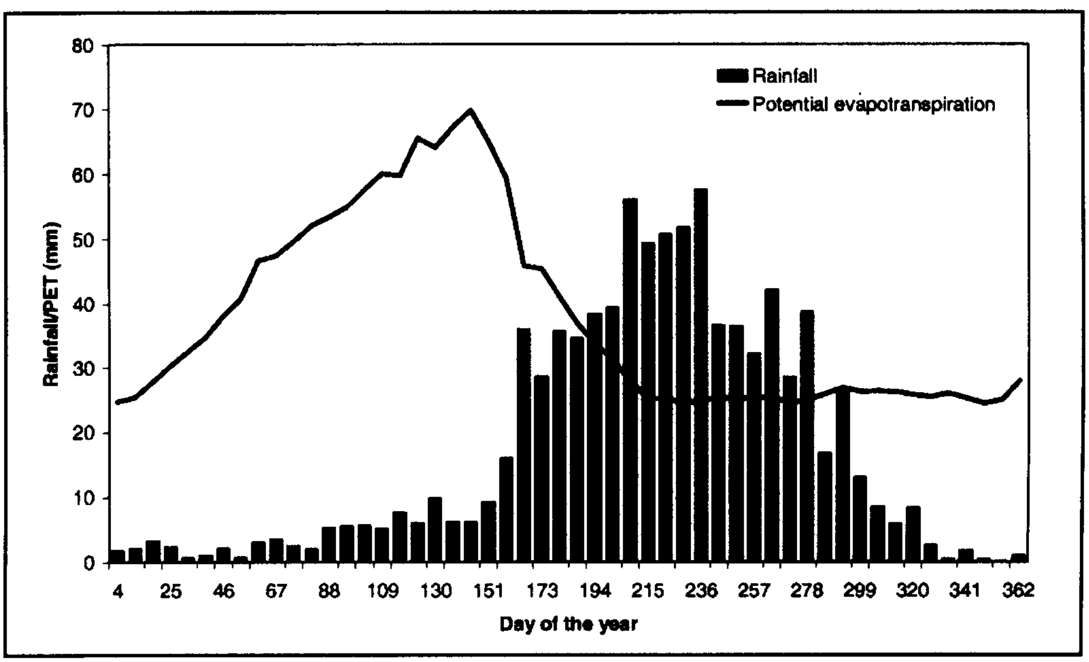

Fig. 2. Mean weekly total rainfall and potential evapotranspiration (PET) for the BW7 watershed site, ICRISAT, Patancheru.

the associated soil erosion could be reliably estimated.

Effect of management on long-term changes in crop yields

Total biomass and grain yield of the two cropping systems decreased over years in both the management treatments with continuous cropping. The decrease in productivity of SB-CP systems over the years was more as compared to the decrease in productivity of the SB/PP intercrop system. The decrease in productivity of the two cropping systems over the years was more on the shallow soil than on the medium-deep soil.

As the crop yields varied from year-to-year with the variability in weather, the yield data of the first three seasons (1995-98 for SB-CP and 1996-99 for SB/PP systems) and the last three seasons (2000-03) were averaged to quantify the percent decline in yields over the years. On the medium-deep soil, the decrease in soybean biomass yield of the SB-CP system was 24–38% and that of chickpea 9–15% across the management treatments (Table 2). Total biomass productivity of the SB-CP system decreased by 18% in the improved management and 31% in the traditional management treatment, indicating the beneficial effect of improved management on the rate of decrease in crop yields. Total biomass productivity of the SB-CP system in the last three years was 21% higher (910 kg ha^{-1}) with improved management than with traditional management. This was because of higher productivity of both the soybean and chickpea crops with improved management as compared to the traditional management. Soybean yields in the last three years were higher by 19% (520 kg ha^{-1}) and chickpea yields by 25% (390 kg ha^{-1}) with improved management compared to the traditional management (Table 2).

On the shallow soil, the decrease in total biomass productivity of the SB-CP system over seasons was more as compared to that on the medium-deep soil, which decreased by 37% in traditional management and by 38% in the improved management treatment (Table 2). In the last three years of the study, the soybean biomass yields were the same in both the management treatments; however, chickpea yields were 30% higher (270 kg ha^{-1}) with improved management than those observed with traditional management. However, the system productivity for total biomass was 8% (270 kg ha^{-1}) higher with improved management than with traditional management.

The trend in grain yield of the SB-CP system over the years was the same as with biomass yield on both the soils; however, the decrease in grain yield was more than that of biomass yield. Mean grain yield of the last three years of the SB-CP system in the improved management was 22% higher (390 kg ha^{-1}) on the medium deep soil and 8% higher (110 kg ha^{-1}) on the shallow soil as

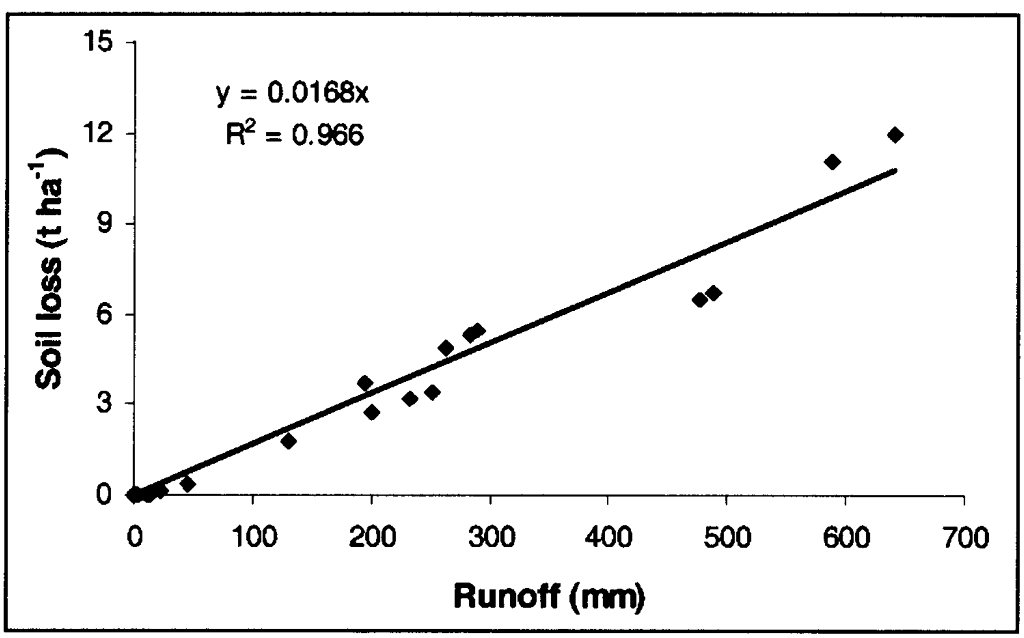

Fig 3. Relationship of soil loss to seasonal runoff from the BW 7 Vertic Inceptisol watershed.

Table 2. Total biomass and grain yield of the soybean-chickpea sequential system in the improved and traditional management treatments during the first three (1995/96 to 1997/98) and the last three years (2001/02 to 2003/04) of study.

Soil depth	Soybean		Chickpea		Soybean + Chickpea	
	Improved	Traditional	Improved	Traditional	Improved	Traditional
Total Biomass yield (kg ha^{-1}) (1995/96 to 1997/98 season)						
Medium depth	4170	4320	2170	1870	6340	6170
Shallow depth	4160	3960	1570	1480	5890	5360
SEd	117.2		129.5		225.0	
2001/02 to 2003/04 season						
Medium depth	3190	2670	1980	1590	5170	4260
Shallow depth	2490	2490	1170	900	3660	3390
SEd	137.2		160.0		255.6	
Grain yield (kg ha^{-1}) (1995/96 to 1997/98 season)						
Medium depth	1590	1710	1160	1020	2750	2710
Shallow depth	1640	1620	800	790	2520	2360
SEd	53.02		105.6		111.7	
2001/02 to 2003/04 season						
Medium depth	1050	880	1130	900	2170	1780
Shallow depth	770	820	630	470	1400	1290
SEd	56.16		95.44		129.7	

SEd = Standard error of the difference between means for comparing management treatments.

compared to the traditional management treatment (Figs. 4a & b and Table 2). Most of the gain in grain yields of the SB-CP system occurred due to yield improvement of chickpea (25-33% higher) with improved management than that of soybean on both the soil types. Higher productivity of chickpea could be attributed to greater soil water storage in the improved management plots at the beginning of the post rainy season compared to the traditional management plots (Fig. 5).

Long-term effect of improved management on productivity of the SB/PP intercrop system for total biomass and grain yield was less than that for the SB-CP system especially on the shallow soil. Total biomass productivity of SB/PP system over seasons decreased by 23% on the medium deep soil and by 29% on the shallow soil across management treatments (Figs. 6a & b and Table 3). Maximum decrease in biomass yields of soybean was up to 18% across soil types and management treatments. Pigeonpea biomass yields over years decreased by 27-41% across soil types and management treatments (Table 3). In the last three years of the study the total biomass productivity of SB/PP system in the improved management was higher by about 10% (480-590 kg ha^{-1}) as compared to the traditional management on both the soils (Table 3).

Grain yield of soybean in the SB/PP system decreased by 30-42% over the years on the medium-deep soil and by 41% on the shallow soil (Table 3 and Figs. 6a & b). Despite large decrease in biomass productivity of pigeonpea over the years, the grain yields of pigeonpea slightly improved by 2-9% over the years . Grain yields of soybean and pigeonpea and their total productivity were not significantly benefited by improved management. Total grain yield productivity of the SB/PP system increased by 4-7% with improved management as compared to the traditional management on the two soils. As the IPM control measures taken were not absolute, the lack of grain yield response of pigeonpea to improved management on the medium deep soil could be attributed to yield loss by pests, which nullified the yield advantages due to improved management.

Decrease in productivity of the two cropping systems over the years could be attributed to the decline in soil fertility due to nutrient removal with continuous cropping and nutrient losses through surface runoff, soil erosion

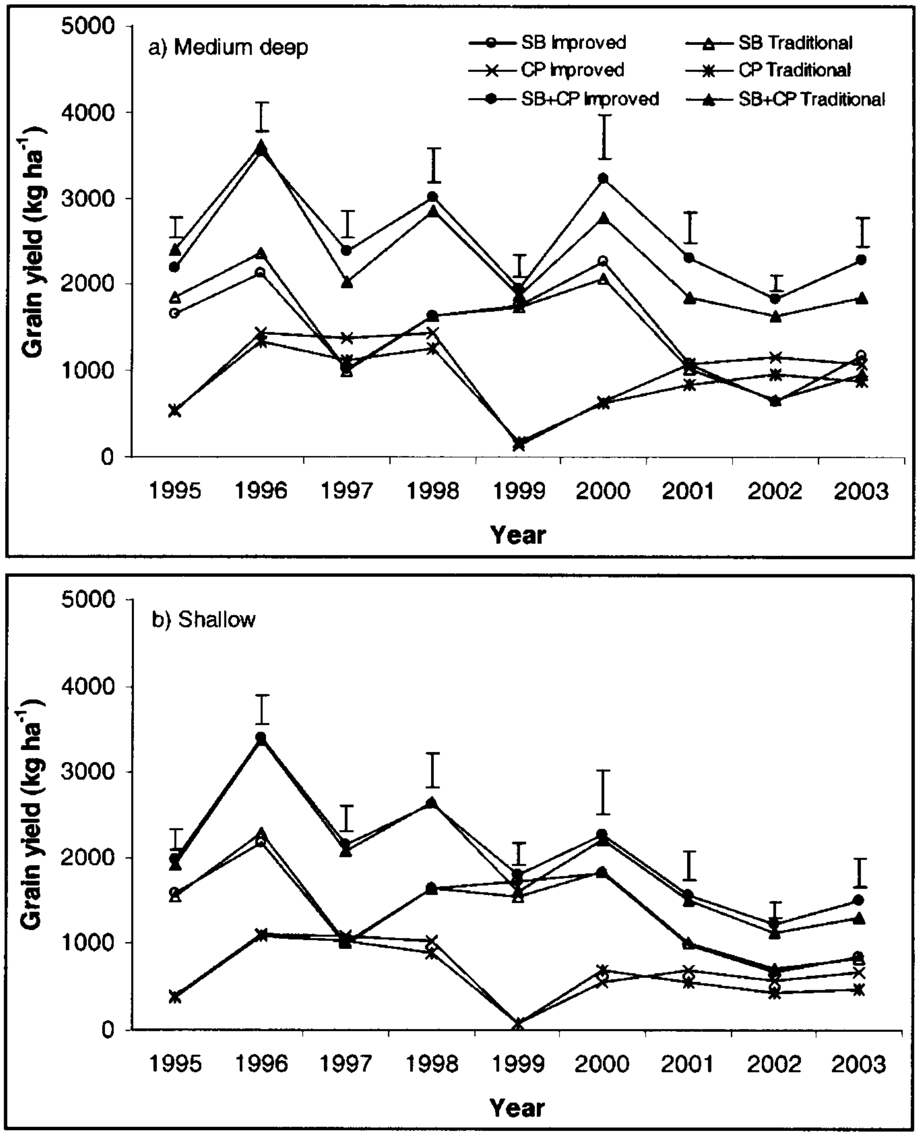

Fig 4. Changes in grain yield of soybean-chickpea sequential system and the component crops on a) the medium deep and b) shallow soil from 1995 to 2003. Vertical bars represent the standard error for the total grain yield of the cropping system.

and leaching without sufficient nutrient replenishment. Even in the improved management treatment, the nutrient additional through crop residues and nitrogen fixation were not sufficient to compensate for nutrient removal. Less decline in the productivity of the SB/PP intercrop system over years is attributed to its low grain yield potential and additions of organic carbon and other nutrients to the soil through greater leaf senescence and roots of pigeonpea crop as compared to the SB-CP sequential system (Wani *et al.,* 2003).

Changes in soil carbon and other nutrients

In 1995 before the beginning of the first rainy season the organic carbon, total N and available P content of the soils in all the four hydrological units was high because the area had been under a grass and bush fallow for many years. The hydrological units in the northern part of the watershed (medium-depth traditional management and shallow-depth improved management) had higher total organic carbon in the soil due to greater density of vegetation in that area compared to the hydrological units lying in the southern part of the watershed (medium-depth improved management and shallow-depth traditional management) (Fig. 1 and Table 4).

After a period of eight years of cropping (1995-2002) there was an overall decline in the organic carbon (OC), total N and available P content of the soil (Table 4) in all the treatments. Additionally the extractable micronutrients (Zn, S and B) contents of soil before the start of season in 2002 were found to be in low range

Table 3. Total biomass and grain yield of the soybean/pigeonpea intercrop systems in the improved and traditional management treatments during the first three (1996/97 to 1998/99) and the last three years (2001/02 to 2003/04) of study. Each data point is mean of three years.

Soil depth	Soybean		Pigeonpea		Soybean + pigeonpea	
	Improved	Traditional	Improved	Traditional	Improved	Traditional
Total biomass yield (kg ha^{-1}) 1996/97 to 1998/99 season						
Medium depth	2570	2740	5590	4590	8060	7230
Shallow depth	2730	2420	5320	4560	7950	6880
SEd	149.8		653.6		685.3	
2001/02 to 2003/04 season						
Medium depth	2550	2235	3640	3370	6190	5600
Shallow depth	2350	2120	3160	2900	5500	5020
SEd	152.1		265.8		400.4	
Grain yield (kg ha^{-1})1996/97 to 1998/99 season						
Medium depth	1110	1260	910	970	2000	2180
Shallow depth	1160	1200	1010	920	2100	2030
SEd	57.9		79.5		123.3	
2001/02 to 2003/04 season						
Medium depth	780	730	990	990	1780	1710
Shallow depth	710	690	990	900	1690	1590
SEd	72.57		83.59		143.5	

SEd = Standard error of the difference between means for comparing management treatments.

indicating depletion of soil fertility over eight years of cropping. Although the differences in OC content of soil in the year 2002 due to land management or cropping systems treatments were statistically non-significant, the improved management treatment plots retained 2.0 t ha^{-1} more total OC in the soil profile compared to the traditional management plots in the medium-deep soil. This benefit of improved management was not observed for the shallow soil. Traditional management retained more OC as compared to the improved system on the shallow soil. The real cause of this reversal in trend is not known, but could be due to greater deep drainage from the shallow soil under improved management resulting in greater loss of OC from the soil profile as compared to the traditional management. The soil under the SB/PP intercrop system generally retained more OC than the SB-CP sequential system, except in the shallow soil under the improved management (Table 5). Over eight years of cropping the SB/PP intercrop system in the traditional management treatment retained more OC compared to the SB-CP system in both the soils (2.4 t ha^{-1} and 6.4 t ha^{-1} more OC in the medium-deep and shallow soils, respectively). Whereas in the improved management treatment, such benefit of SB/PP system was observed only for the medium deep soil, which amounted to 4.8 t ha^{-1} more OC in the soil as compared to the SB-CP system. Higher OC in the soil under SB/PP system as compared to the SB-CP system is attributed to greater additions of organic matter through leaf senescence and rooting of pigeonpea as observed by Wani *et al.* (2003) for the Vertisol.

Conclusions

Improved management of the Vertic Inceptisol decreased surface runoff by 24-27% and soil loss by 44-47% as compared to the traditional management. Total productivity of both the cropping systems for biomass and grain yield decreased over time, however, the decrease in productivity of the SB/PP system was less than that of the SB-CP system in both the management treatments. In the last three years of study, total grain yield productivity of SB-CP system was 22% higher on the medium-deep soil and 8% higher on the shallow soil with improved

Table 4. Soil organic matter (OC), total N and extractable elements in various soil depths in the two management treatments at the beginning of cropping seasons in 1995 and 2002.

Soil depth	Management	OC (t ha^{-1})		Total N (mg kg^{-1})		Extractable elements (mg kg^{-1}) Olsen's P		Zn	S	B
		1995	2002	1995	2002	1995	2002	2002	2002	2002
		0-90 cm soil depth				0-15 cm soil depth				
Medium	Traditional	74.0	49.1	401	298	1.31	0.31	0.64	7.4	0.19
	Improved	54.9	51.1	402	380	1.96	0.58	0.80	4.5	0.15
Shallow	Traditional	61.2	55.3	412	356	1.83	0.75	0.60	7.1	0.22
	Improved	87.7	53.6	401	427	1.93	0.60	0.83	8.1	0.18
	SEd	13.32	3.14							

SEd = Standard error of the difference in means. Critical limits of nutrients to be in low concentration: Olson's P <5.0 mg kg^{-1}; Zn < 0.75 mg kg^{-1}; S < 10 mg kg^{-1}; and B < 0.58 mg kg^{-1}.

management than with traditional management. Total grain yield of the SB/PP inter-crop system was marginally higher by 4-7% with improved management on both the soil types. Over eight years of cropping, organic carbon (OC), total N and available P content of the soil declined in all the treatments; and in 2002 the extractable micronutrients (Zn, S and B) of soil were found to be deficient. After eight years of cropping, improved management retained 2.0 t ha^{-1} more OC compared to the traditional system; and SB /PP system retained 2.4 to 6.4 t ha^{-1} more OC compared to the SB-CP system in the medium-deep soil, but not in the shallow soil. It is

Table 5. Soil organic matter (OC) and total N content of the top 90 cm of soil under the two cropping systems at the beginning of cropping season in 2002.

Soil depth	Cropping system	OC (t ha^{-1}) Traditional	Improved	Total N (mg kg^{-1}) Traditional	Improved
		0-90 cm soil depth			
Medium	SB-CP	47.9	48.7	286	351
SB/PP	50.3	53.5	310	409	
Shallow	SB-CP	52.1	55.6	355	417
	SB/PP	58.5	51.5	358	437
SEd	4.59	-			

SEd = Standard error of the difference in means.

concluded from this study that for improving and stabilizing productivity of the soybean-based cropping systems on Vertic Inceptisols, in addition to improved land and water management, more balanced nutrition of crops through additions of organics and inorganics including application of micronutrients would be required than the low input practice evaluated in this study.

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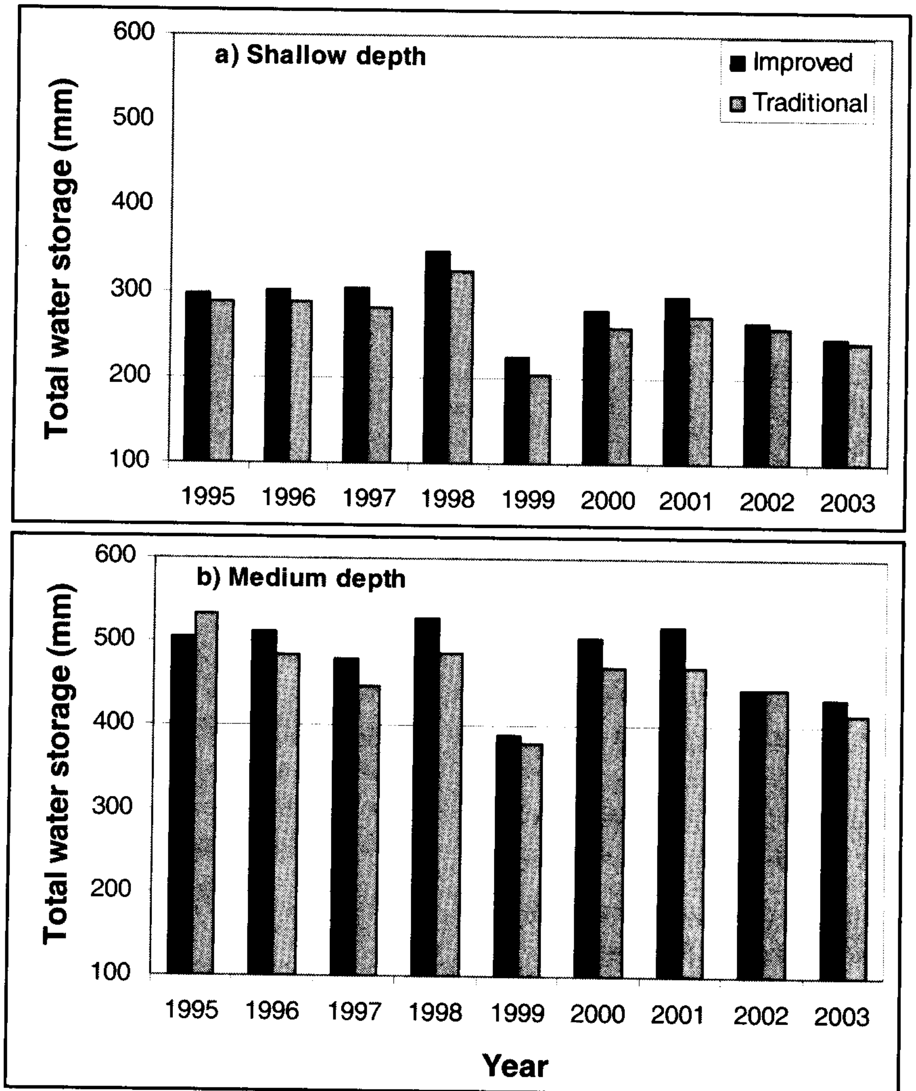

Fig 5. Total water stored in the top 90 cm soil profile for the (a) shallow soil and in the top 120 cm for the (b) medium-deep soil as influenced by traditional and improved management. Observations taken at the beginning of the postrainy seasons from 1995 to 2002.

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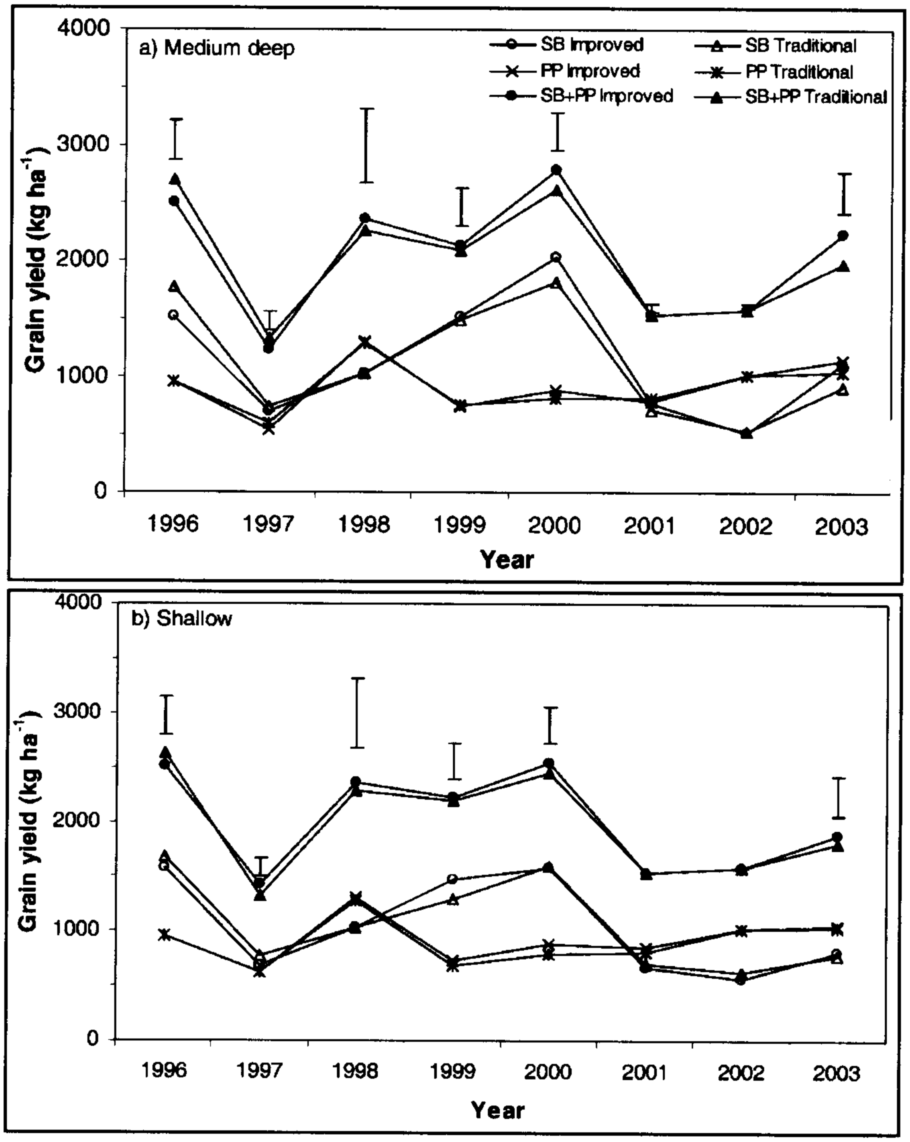

Fig 6. Changes in grain yield of soybean/pigeonpea intercrop system and the component crops on a) the medium deep and b) shallow soil from 1996 to 2003. Vertical bars represent the standard error for the total grain yield of the cropping system.

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