Journal of the Indian Society of Soil Science, Vol. 61, No. 2, pp 79-88 (2013)

Effect of Land Management and Cropping Systems on Runoff, Soil Loss, Soil Water Dynamics and Crop Yield in a Vertisol of Central India

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Sustainable crop production under rainfed condition can be achieved by conservation of excess rainwater and its efficient recycling. The rainwater can be conserved *ex-situ* in natural or man-made water harvesting structures. *In-situ* conservation of rainwater can be achieved through various tillage and landform treatments. A field experiment was conducted for three years from 2003-04 to 2005-06 on a Vertisol (Typic Haplustert) in a mini-watershed at the research farm of the Indian Institute of Soil Science, Bhopal to study the effect of broad bed and furrow (BBF) and flat on grade (FOG) land management treatments on the runoff and soil loss, and to evaluate the productivity of five soybean and maize based sole and intercropping systems under the two land management treatments. The results showed that runoff and soil losses from BBF were lower by 24-32% and 31-55%, respectively, than that from the FOG treatment during the study period. Further, the BBF retained 14 to 23 mm higher soil water in 90 cm soil profile during the later phase of crop growth after the withdrawal of monsoon and produced higher crop yield than the FOG treatment. The total system productivity was found to be higher in maize than soybean based cropping systems in two out of three years of the study. The study provides an option for crop diversification from the present soybean-wheat system to maize-chickpea, soybean/maize-chickpea or maize/pigeon pea intercropping system for the Vertisols of central India.

Key words: Broad bed and furrow, Vertisols, runoff, soil loss, soil water dynamics, cropping system

Rainwater, a crucial natural resource, is the key input in Indian agriculture. Sixty per cent of the total cropped land in the country is rain dependent (Anonymous 2007). For getting a sustainable crop production system under rainfed condition, the conservation of rainwater and its efficient recycling are imperative. The rainwater can be conserved either *in-situ* or *ex-situ* in natural or manmade structures for supplemental irrigation. *In-situ* rainwater conservation can be carried out either though tillage or land surface management (Singh *et al.* 2000). Among the various land surface management practices like raised and sunken bed, ridges and furrow, *etc*., developed for Vertisols, broad-bed and furrow (BBF) system is very promising in controlling surface runoff, reducing the soil loss through erosion and increasing infiltration (Pathak *et al.* 1985; Singh *et al.* 1999). The BBF landform management system essentially reduces the velocity of runoff water and consequently increases opportunity time for water to infiltrate and reduces sediment losses. Further, during the period of heavy rainfall the furrows allow excess water to drain safely from the plots and thus avoid water congestion to the crop (Kampen 1982). Average annual rainfall in central India varies from 750 to 1300 mm, of which more than 80% is received during the monsoon between June to October (Singh *et al.* 2007). This rainfall far exceeds the average evapo-transpiration of 650 mm for this period. The surplus amount of rainfall is lost either through runoff or deep drainage. There is an urgent need to manage the water resources of Vertisols of this region possibly through adoption of improved land management practices, which will de-

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crease runoff and soil erosion and concomitantly improve crop yield in deep Vertisols.

Stagnation of productivity of soybean based production systems due to erratic distribution of monsoonal rain and incidence of new insect-pests and diseases is leading to under-utilization of land, water, nutrient and climatic resources. Under this situation the crop diversification in the rainy season can be a viable option for stabilizing and enhancing productivity of the system. In winter season, it has been found that chickpea performs better than high water and nutrient requiring wheat crop. In addition, harvesting of runoff water in storage pond and its efficient utilization through supplemental irrigation to the rainy season crop in case of early withdrawal of monsoon and pre-sowing irrigation to the winter crop holds the promise for increasing the total system productivity and stability (Wani *et al*. 2003a). In order to ensure a pay-off from nutrients, all round augmentation of water resource with watershed as a unit of development is imperative. Therefore, an experiment was conducted to (i) assess the effect of landform management on runoff and erosion, (ii) study soil water dynamics as influenced by land form management and cropping system, and (iii) evaluate the productivity of five soybean and maize based sole and intercropping systems in a Vertisol of central India.

Materials and Methods

Site, Soils and Experimentation

A field experiment was conducted for three years (2003-04 to 2005-06) on broad bed and furrow (BBF) and flat on grade (FOG) land treatments with five different cropping systems *viz.*, Soybean [*Glycine max* (L.) Merr.] – chickpea [*Cicer arietinum* (L.)], maize [*Zea mays* (L.)]- chickpea, soybean/ maize intercropping– chickpea, soybean/ pigeon pea [*Cajanus cajan* (L.) Millsp.] intercropping and maize/ pigeon pea intercropping, and two irrigation levels (only pre-sowing (PS) and PS + one post-sowing irrigation at flowering stage) on a mini-watershed at the experimental farm of Indian Institute of Soil Science, Bhopal, Madhya Pradesh (23°18′ N, 77°24′ E, 485 m above mean sea level). The watershed consisted of a water harvesting pond of around 1.5 ha surface area placed at the lowest elevation and a catchment area of around 10 ha. Slope of the catchment area varied between 0.3 to 0.6%. The two land management treatments BBF and FOG were placed in two blocks in the catchment area after proper leveling the field (Fig. 1). The runoff and sediments were recorded using runoff and sediment samplers placed at the final drainage points of both BBF and FOG. Soil of the experimental site was deep heavy clay (Typic Haplustert). The initial soil samples analyzed from the top 15 cm depth were low in organic carbon (4.8 g kg^{-1}), available N (112 mg kg^{-1}) and available P (2.6 mg kg^{-1}) and high in available K (230 mg kg^{-1}). The pH, CEC, bulk density of the surface soil (0-15 cm) were 7.7, 46 cmol(p^+) kg^{-1} soil and 1.34 Mg m^{-3}, respectively, while water holding capacity at saturation, field capacity (-33 kPa) and permanent wilting point (-1500 kPa) were 62.8, 38.9 and 24.6% (v/v), respectively. The climate of the experimental site was hot sub-humid with a mean annual rainfall of 1130 mm and potential evapo-transpiration of 1400 mm. The daily rainfall, maximum and minimum temperature recorded during the rainy seasons of 2003 to 2005 are depicted in Fig. 2.

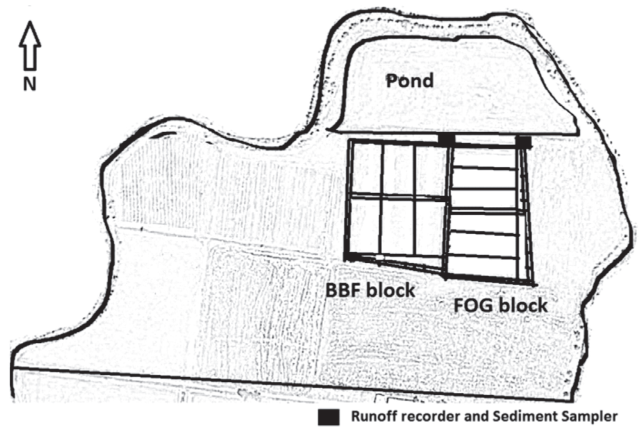

Fig. 1. Field layout of the watershed showing the catchment area, distribution of plots, water harvesting pond and location of the runoff and soil loss measuring devices

The BBF landform was prepared with the help of a tractor drawn BBF former along the key lines drawn based on a topographic survey. The width of the broad bed was 1.0 m with 0.5 m wide furrows on either side of the bed. The FOG plots were prepared by cultivating the soil with two passes of duck foot tyne sweep cultivator along the slope of the land for proper tilth and crops were sown by seed drill. The FOG treatment was like traditional cultivation system followed by farmers in this region. In the first year (2003-04) pigeon pea monocrop was taken in lieu of maize/pigeon pea intercropping. In rainy seasons, crops were grown rainfed while in winter season chickpea was grown with two irrigation levels, (i) one pre-sowing (PS) (I_1) and (ii) one PS + one irrigation at flowering stage (I_2). The water stored at the water harvesting pond of the watershed was recycled for irrigating chickpea. The experiment was laid on a split plot design with three replications where crop-

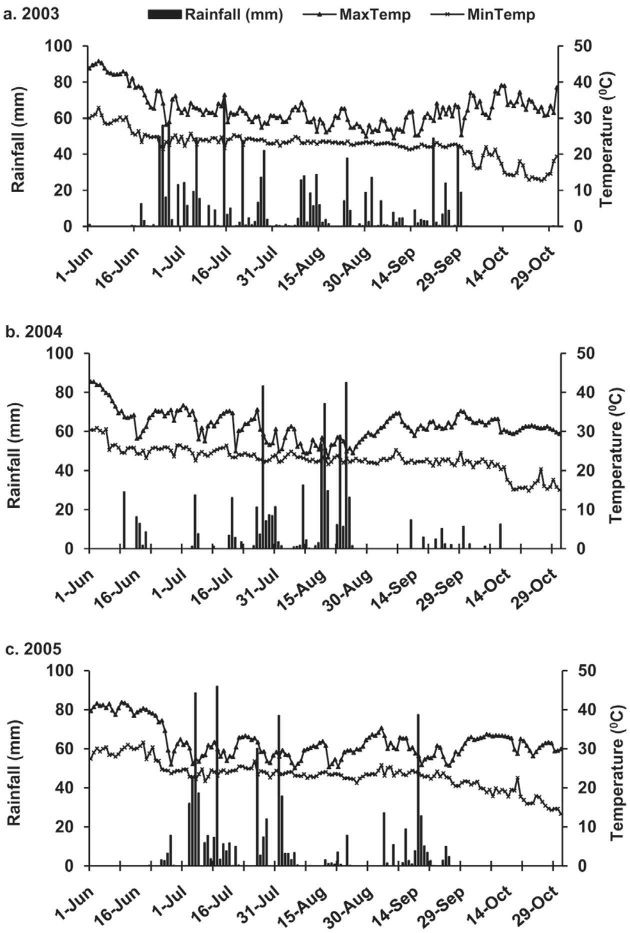

Fig. 2. Daily rainfall, maximum and minimum temperature during the rainy seasons of the experimental years

ping systems were taken as a main plot and irrigation levels as a subplot treatment. The sub plot size was 10 m × 4.5 m. Recommended doses of NPK fertilizer were applied to each crop and farmyard manure @ 5 t ha^{-1} was applied once in a year to the rainy season crop. The recommended N:P:K doses for soybean, maize, pigeonpea and chickpea were 30:26:25, 120:26:33, 30:26:33, 30:26:33 kg ha^{-1}, respectively. In soybean, pigeonpea and chickpea entire dose of fertilizer were applied as basal while in maize entire dose of P, K and 50% of N fertilizer was applied as basal and remaining 50% N was top dressed 20 days after crop establishment. The N, P and K were applied as urea, single super-phosphate and muriate of potash, respectively. In the rainy season, soybean, maize and pigeonpea were sown during the last week of June or first week of July after onset of monsoon while in the winter season chickpea was sown in the second week of November. The necessary plant protection and other management practices were followed during crop growth. Hand weeding was done one month after sowing to keep the field weed free. Crops were harvested manually at their physiological maturity and grain yield was recorded from net plot harvest. To compare system performance, soybean equivalent yield (SEY) was calculated by converting the yield of each crop into equivalent soybean yield on a price basis, using the formula:

$$\text{SEY (of crop x)} = Y_x (P_x/P_s)$$

where, Y_x is the yield of crop x (Mg ha^{-1}), P_x the price of the crop x, and P_s is the price of soybean. The current market price of these crops was used in calculating SEY, and the SEY of rainy season and winter crops were added to determine total system productivity (TSP).

Measurements

Runoff from each landform treatment was measured with automatic runoff recorder (Thalimedes, OTT, Messtechnik GmbH & Co., KG, Germany) installed on a H-flume constructed at the lowest contour point. The height of the water passing through the H-flume was continuously recorded by a float operated shaft encoder with digital data logger which was later interpreted in terms of runoff volume associated with each rainfall event (Pathak 1999). Runoff was summed to calculate cumulative runoff. Automatic pumping sediment sampler developed at International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad, was used to monitor the temporal changes in sediment losses from each runoff event. The samplers collected runoff water with suspended sediments passing through the H-flume and stored in plastic collection bottles at 20 min interval. The sediment was flocculated by adding 1 *N* HCl @ 10 mL per litre of runoff volume and dried in oven to estimate the suspended particle content. The sediment concentration obtained from each bottle was used for the calculation of total sediment losses associated with each runoff events. The runoff and soil loss were recorded during the rainy seasons. Rainfall was recorded at an automatic weather station situated adjacent to the watershed using a tipping bucket recording type rain gauge. The bulk density in each replicate was determined by a core sampler with core of 6 cm height and 8.5 cm diameter, down to a soil depth of 30 cm at 7.5 cm interval.

Soil water content up to a depth of 90 cm at 15 cm interval was determined thermo-gravimetrically at regular interval during the crop growth period in 2003 and 2004 for all the subplots and replications. The water content of individual soil depth determined on weight basis was multiplied with corresponding bulk density and depth of the soil layer to obtain the profile water storage. Analysis of variance (ANOVA) was carried out using split plot design (Gomez and Gomez 1984) for comparing means of main and interaction effect using least significant difference with 5% significant level. The significance of the mean difference between the two land management practices for a variable were calculated by students t-test at 5% significance level assuming two samples of unequal variance using the data analysis tool pack of MS-excel.

Results and Discussion

Weather

Total rainfall received during the rainy season of 2003 (June to October) was 1058 mm, which was slightly higher than the long-term average rainfall of 1005 mm (1980-2003) for the rainy season, distribution of rainfall was quite uniform. Except for the month of August and October, the monthly rainfall received in June, July and September was higher than the long-term mean monthly rainfall. Crops did not suffer from any severe water deficit during 2003. Daily maximum temperature during this period varied between 24.5 and 45.8 °C while the daily minimum temperature ranged between 12.7 and 32.9 °C.

Total rainfall received during the rainy season of 2004 was 798.2 mm, which was about 20% lower than the long-term average rainfall. Distribution of rainfall was also not uniform during the season. The month of June received only 8.5% whereas July and August received 83% of the total seasonal rainfall, and September and October received the remaining amount (8.5%). Low and erratic distribution of rainfall adversely affected the performance of soybean owing to moisture stress during the grain-filling stage of the crop.

Total rainfall received during the rainy season of 2005 was 946.2 mm. The onset of monsoon was very late in 2005. The month of June received only 26.7 mm *i.e.* 2.8% of the seasonal total rainfall. Most of the rain was received in the month of July (55.7%) whereas the share of August was only 18.4% of the seasonal total. During the grain filling stage i.e. the 2nd week of September, the crops received a good rainfall. About 23% of the seasonal rainfall was received in September.

Surface Runoff and Soil Loss

Runoff from the BBF was less than that from the FOG in all the three years of study. Of the total rainfall received during the rainy seasons of 2003, 2004 and 2005, about 20.3, 23.0 and 26.1%, respectively, was lost as runoff from FOG compared with 15.4, 15.5 and 18.7% from BBF. This might be attributed to the reduced speed of runoff in BBF than in FOG plot due to gentle slope, which have resulted in higher opportunity time for water to infiltrate in BBF than FOG treatment. Besides this, Vertisols under BBF system contains more transmission pores than flat bed system (Jayashree and Rao 2002) which might have increased the infiltration rate in BBF. The quantity of runoff in both the systems was more in 2003 and 2005 than that in 2004 owing to higher rainfall associated with more number of medium intensity long-duration rainy days in 2003 and 2005 (Table 1 to 3). A total of 16 runoff events were recorded in

Table 1. Effect of landform treatments on runoff and soil losses from the runoff events occurred during the rainy season of 2003

Date	Rainfall (mm)	Runoff (mm)		Soil loss (kg ha^{-1})	
		BBF	FOG	BBF	FOG
01/07/2003	26.8	1.9	0.0	23.0	0.0
04/07/2003	32.2	4.4	1.6	52.6	21.8
06/07/2003	63.0	25.4	34.0	305.1	449.2
07/07/2003	16.0	6.5	5.9	78.4	77.6
18/07/2003	78.0	29.8	46.6	357.8	615.5
22/07/2003	49.0	20.0	20.0	240.5	263.6
28/07/2003	76.0	22.8	23.8	273.5	314.7
10/08/2003	59.0	6.0	9.3	72.2	123.2
12/08/2003	18.0	1.0	4.9	11.7	65.1
13/08/2003	12.6	0.6	3.5	7.6	46.1
14/08/2003	29.6	0.0	15.6	0.0	205.9
15/08/2003	12.4	0.0	1.7	0.0	22.7
25/08/2003	46.6	0.0	15.1	0.0	198.9
21/09/2003	56.0	13.9	0.0	166.4	0.0
25/09/2003	26.0	5.7	0.0	68.7	0.0
30/09/2003	66.8	24.9	32.8	298.4	432.7
Seasonal total	1058.0	163.0	214.9	1956.0	2836.9

Table 2. Effect of landform treatments on runoff and soil losses from different runoff events occurred during the rainy season of 2004

Date	Rainfall (mm)	Runoff (mm)		Soil loss (kg ha^{-1})	
		BBF	FOG	BBF	FOG
06/07/2004	7.6	0.1	0.1	0.3	0.5
17/07/2004	26	0.3	0.3	1.7	3.0
15/08/2004	53.4	35.6	52.5	224.0	535.6
16/08/2004	74.2	13.9	22.5	62.7	159.7
20/08/2004	58.0	21.2	32.2	122.8	273.6
21/08/2004	11.4	0.5	0.3	2.8	2.8
22/08/2004	85.0	19.4	27.9	79.6	167.6
23/08/2004	26.2	28.9	37.0	140.9	240.0
24/08/2004	1.4	4.2	9.2	22.1	73.3
Seasonal total	798.2	124.0	183.3	657.3	1466.0

Table 3. Effect of land surface management treatments on runoff and soil losses from different runoff events occurred during the rainy season of 2005

Date	Rainfall	Runoff (mm)		Soil loss (kg ha^{-1})	
	(mm)	BBF	FOG	BBF	FOG
05/07/2005	92.2	19.0	3.7	2.0	52.6
06/07/2005	45.0	0.1	15.0	196.5	245.6
11/07/2005	104.9	62.9	96.8	572.3	1334.2
13/07/2005	4.5	0.0	2.7	5.4	56.3
25/07/2005	58.6	0.3	3.0	3.9	37.5
27/07/2005	22.2	6.4	6.7	45.6	81.6
01/08/2005	79.4	57.9	82.2	356.4	897.3
14/09/2005	8.5	0.2	2.3	2.1	28.7
15/09/2005	78.8	29.4	31.4	212.2	374.6
16/09/2005	29.2	0.5	1.0	3.2	12.3
Seasonal total	946.2	177.3	247.3	1402.1	3123.6

2003 whereas only 9 runoff events were recorded in 2004. In 2004, more than 95% of the total runoff volume was generated in 5 runoff events occurred in a short span of 8 days between 15th to 23rd August. But in 2003 and 2005 occurrences of runoff events were much more evenly spaced. Total runoff events in 2005 were ten of which four events accounted for more than 90% of the total runoff for the year. Corresponding to the runoff, soil loss was also more in 2003 and 2005 compared with 2004 for both the land surface management treatments. Soil losses through runoff from BBF were more than that from FOG in all the three years of experimentation. The data showed that BBF landform treatment reduced soil loss to a greater extent (31 to 55%) than its reduction in runoff volume (24 to 32%) as compared with that of FOG over the years. This can be ascribed to lower concentration of sediments in runoff water coming from the BBF than from FOG as velocity of flow of the runoff water was generally lower in BBF. The average sediment concentration pooled over the years in the runoff water from the BBF was 0.840 g L^{-1} while it was 1.128 g L^{-1} for the FOG treatment. Srivastava and Jangwad (1988) and Singh *et al.* (2007) have also shown that runoff and soil loss were remarkably reduced in BBF land surface management treatment in a long-term watershed study on a Vertisol.

Soil Water Dynamics and Moisture Extraction by Crops

The moisture storage up to 90 cm soil depth during the rainy season of 2003 ranged between the field capacity and permanent wilting point (PWP) in all plots (Fig. 3). Even in later phase of crop growth, moisture storage in the root zone remained higher than the PWP moisture storage (262 mm). There was practically no soil water stress to crops during the growing season of 2003. The average water storage in the later part of crop growth (beyond 64 days after sowing) was significantly higher in BBF than FOG treatment, but in the early growth period (up to 48 DAS) the difference in water storage between the land treatments was not clear. Heavy rainfall during this period might have masked the treatment effects. Differences in water storage in 90 cm soil profile between the land treatments during the later part of the crop season ranged from 14 to 23 mm (Fig. 3). Higher moisture in BBF in later part of the season might be attributed to its more gradual slope and lower loss of rainwater through runoff. After the withdrawal of

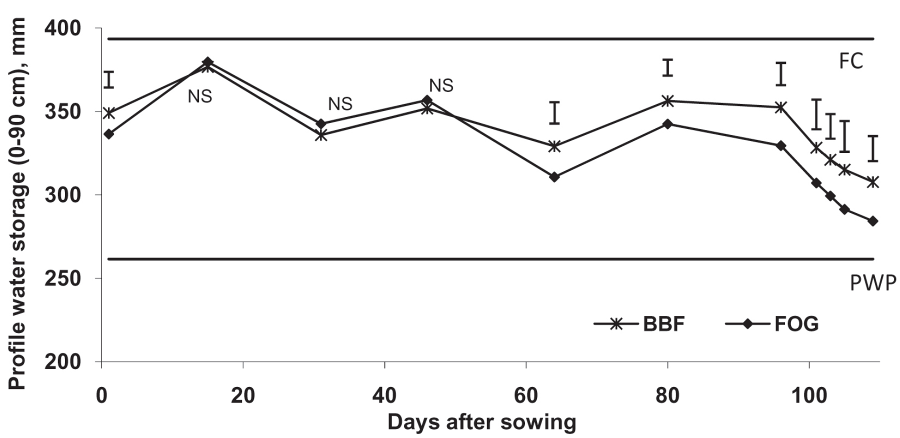

Fig. 3. Temporal variation of soil water storage (0-90 cm depth, averaged over cropping systems) as influenced by land management treatments during the rainy season 2003
Vertical lines represent *LSD* $(P < 0.05)$ between the treatments
NS = not significant

Table 4. Depletion of soil moisture after the withdrawal of monsoon in 2003 and 2004 as affected by cropping system under BBF and FOG land treatment

Cropping systems	Moisture depletion from 0-90 cm depth (mm)			
	2003 (14 days drying cycle)		2004 (28 days drying cycle)	
	BBF	FOG	BBF	FOG
Sole soybean	40.8	42.4	62.3	59.3
Soybean/maize intercropping	37.7	35.6	59.0	56.0
Sole maize	33.3	35.0	55.6	52.6
Sole pigeon pea	60.4	57.3	70.3	76.6
Soybean/pigeon pea intercropping	51.2	55.8	74.5	71.5
LSD (P=0.05)	11.3	10.5	6.2	7.5

monsoon, the soil moisture contents of the profile were measured every alternate day for two weeks to study the moisture depletion pattern during a drying cycle in the year 2003. The results showed that the depletion of soil moisture during the two weeks drying period was significantly higher in the sole pigeon pea and soybean/pigeon pea intercropping compared with sole soybean, sole maize and soybean/maize intercropping (Table 4). Depletion of moisture during this period was the highest under the sole pigeon pea treatment on BBF. Similar results were recorded under both BBF and FOG landform treatments. This was due to higher extraction of moisture by pigeon pea, which was approaching maximum vegetative stage during that period, compared with the other two crops *viz*., soybean and maize, which were near maturity at that time. Besides this, the deep root system of pigeon pea extracted more water from deeper soil layers than the other crops.

In 2004, moisture storage in the profile decreased slightly during the first week after sowing and thereafter it increased in all the plots in the month of July (Fig. 4) with the increase in rainfall. Up to the middle of August, treatment effects on water storage were not clear and it followed the rainfall distribution pattern. Among the two land treatments, BBF often retained slightly higher water in the profile than the FOG treatment after 71 DAS. This might be due to higher infiltration and better retention of water in BBF than FOG treatment. Singh *et al.* (1999) also reported higher water storage in BBF land treatment during rainy season in soybean-chickpea rotation on a Vertic Inceptisols. At the time of maturity (92 DAS) in FOG the average moisture storage in the profile fell below permanent wilting point. Like the earlier year, the depletion of water after the withdrawal of monsoon was significantly higher in soybean/pigeonpea and maize/pigeonpea intercropping systems compared

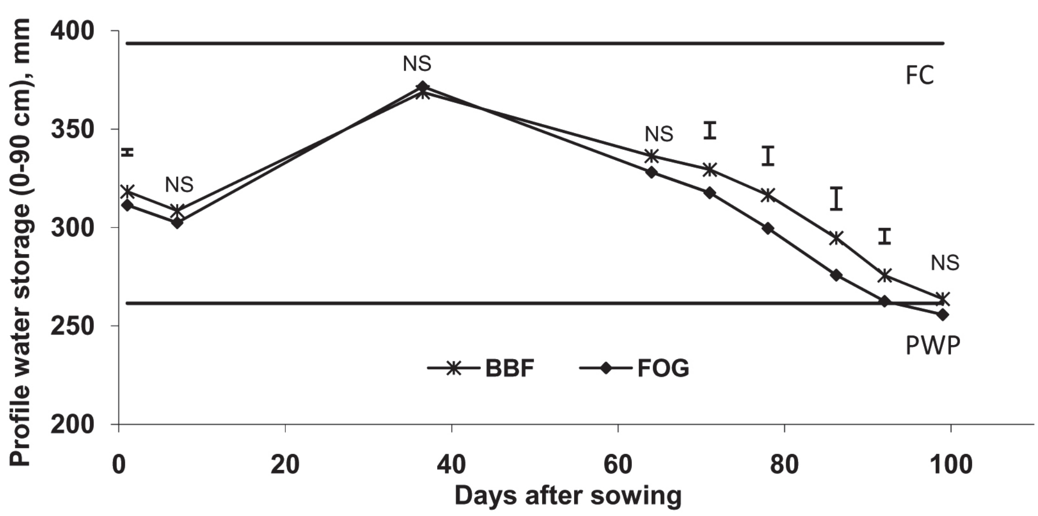

Fig. 4. Temporal variation of soil water storage (0-90 cm depth, averaged over cropping systems) as influenced by land management treatments during the rainy season 2004
Vertical lines represent *LSD* $(P < 0.05)$ between the treatments
NS = not significant

Table 5. Effect of land management on bulk density of the soil after three crop cycles

Depth (cm)	Bulk density (Mg m^{-3})	
	BBF	FOG
0-7.5	1.15	1.27**
7.5-15.0	1.35	1.37^{NS}
15.0-25.5	1.47	1.46^{NS}
22.5-30.0	1.51	1.50^{NS}

**Significantly different *($P < 0.05$)* between the land management treatments
^{NS}Not significant

with sole maize, sole soybean and soybean/maize intercropping systems in both BBF and FOG land management treatments (Table 4).

Bulk density

The effect of the cropping system on bulk density (BD) of the soil measured up to 30 cm depth after three crops cycles was not conspicuous but the land treatment showed clear effect on the BD of the soil at top 7.5 cm depth. At 0-7.5 cm depth, BD was significantly less in BBF (1.15 Mg m^{-3}) than that in FOG (1.27 Mg m^{-3}) land treatment (Table 5).

Yield of Rainy Season Crops

Yield of the rainy season crops and equivalent yield of the crops expressed in terms of SEY under different cropping systems are presented in table 6. In the first year grain yields of soybean in sole soybean treatment were 1830 and 1580 kg ha^{-1} in BBF and FOG land treatments, respectively. Thus, BBF registered 15.8% higher grain yield of soybean than FOG whereas Rajput *et al*. (2009) reported 55% higher yield of soybean on BBF than that on flatbed system in a Vertisol of Madhya Pradesh. Similarly, grain yield of maize in sole maize treatment (3637 kg ha^{-1}) under BBF was 11.8% higher than under FOG land configuration (3250 kg ha^{-1}). In soybean/maize and soybean/pigeon pea intercropping systems, grain yield of soybean and maize were also higher in BBF than FOG. Similarly, from their two years study on rainfed sunflower on a Vertisol, Paulpandi *et al.* (2008) reported a 27.3 to 30.0% increase in grain yield in BBF over flat bed method. In both soybean/maize and soybean/pigeon pea intercropping systems soybean yield was considerably less than that from the sole soybean treatment because of reduced plant population in intercropping. Maize yield reduced in intercropping compared to the sole crop by 200 and 240 kg ha^{-1} in BBF and FOG, respectively, because of shading and competition for resources with the companion crop. Among the different cropping systems, the SEY of the rainy season crops were the highest in soybean/pigeon pea intercropping followed by pigeonpea sole cropping and it was the lowest in maize-chickpea system. The SEY in maize-chickpea system was lower

Table 6. Grain yield (kg ha^{-1}) and soybean equivalent yield (SEY, kg ha^{-1}) of rainy season crops under different cropping systems

Treatments	BBF				FOG			
	Soybean	Maize	Pigeon pea	SEY	Soybean	Maize	Pigeon pea	SEY
Year: 2003								
Sole soybean	1830	-	-	1830b	1580	-	-	1580b
Sole maize	-	3640	-	1210c	-	3250	-	1080c
Soybean/maize intercropping	650	3430	-	1790b	560	3010	-	1570b
Soybean/pigeon pea intercropping	740	-	1880	2620a	660	-	1600	2260a
Sole pigeon pea	-	-	1910	1910b	-	-	1646	1646b
Year: 2004								
Sole soybean	640	-	-	640e	540	-	-	540e
Sole maize	-	4260	-	2070c	-	3660	-	1780c
Soybean/maize intercropping	290	2250	-	1380d	250	1940	-	1190d
Soybean/pigeon pea intercropping	630	-	1740	2370b	520	-	1510	2030b
Maize/pigeon pea intercropping	-	4320	1290	3390a	-	3710	1170	2980a
Year: 2005								
Sole soybean	1530	-	-	1530d	1340	-	-	1340d
Sole maize	-	5830	-	3160c	-	5020	-	2730c
Soybean/maize intercropping	1000	4140	-	3240bc	970	3360	-	2790bc
Soybean/pigeon pea intercropping	1860	-	1270	3530b	1580	-	1010	2910b
Maize/pigeon pea intercropping	-	5650	1090	4510a	-	5380	900	4110a

Figures followed by different letters in a column for a particular year are significantly different at 5% level

Table 7. Yield of chickpea as influenced by irrigation and previous crops

Parameter	Grain yield of chickpea (kg ha^{-1}) pooled over the years	
	BBF	FOG
Irrigation		
I_1- One pre-sowing (PS)	1330b	1060b
I_2-PS + one irrigation at flowering stage	1627a	1323a
Cropping systems		
Soybean + chickpea	1530a	1203a
Maize + chickpea	1473a	1170a
Soybean/maize + chickpea	1430a	1196a

Figures followed by different letters in a column are significantly different at 5% probability level

owing to relatively low market price of maize compared to soybean in that year. In both the land management treatments the SEY of the cropping systems followed similar trend.

The grain yields of soybean in sole soybean treatment were 640 and 540 kg ha^{-1} in BBF and FOG land treatment, respectively during the year 2004. Low yield of soybean during the year 2004 was mainly due to sudden heavy infestation of insect-pests in the pod filling stage which caused substantial damage to the crop. The yield reduction in soybean was a common observation at many places in this region during this year. Grain yield of maize in sole maize treatment under BBF was 16 and 16.5% higher than the sole maize under FOG in 2004 and 2005, respectively. In soybean/maize and soybean/pigeon pea intercropping systems, grain yield of soybean and maize was also higher in BBF than FOG both in 2004 and 2005. Lesser loss of fertile top soil through runoff from the BBF system and lower bulk density of the top soil might be the reasons for higher yield in BBF than in FOG. Higher yield of crops in BBF might also be ascribed to higher retention of moisture in the grain filling stage, less water stagnation, better aeration in the rooting zone. Selvaraju *et al.* (1999) and Wani *et al.* (2003b) also reported similar observations.

In both the land treatments, the yield of pigeon pea was less when it was intercropped with maize than with soybean. The SEY of rainy season crops was also higher in BBF than FOG. The SEY in 2004 and 2005 was the highest in maize/pigeonpea intercropping followed by soybean/pigeonpea intercropping and was the lowest in sole crops both in the BBF and FOG.

Grain Yield of Chickpea

In the winter season chickpea was grown in three cropping systems where pigeon pea was not included with two irrigation levels. The average grain yield of chickpea was 24.1% higher in BBF than FOG. Similarly on a Vertisol of Ethiopian highland, Agegnehu and Sinebo (2012) recorded 45% higher seed yield of chickpea in BBF system than flat seed bed land system. In both the land surface management treatments yield variation of chickpea was not significant among the three cropping systems (Table 7). Thus, chickpea yield was not significant influenced by the residual effect of the previous crops. However, as expected the irrigation treatments showed significant variation in chickpea yield. The grain yield of chickpea in I_2 (one pre-sowing + one post-sowing irrigation) was significantly greater (23.4%) than that in I_1 (only pre-sowing irrigation) in both the land configurations. This shows that one post sowing irrigation at flowering stage of chickpea is beneficial for harnessing the yield potential of chickpea in this region.

Total System Productivity

Total system productivity (TSP) expressed as SEY was significantly higher in I_2 than in I_1, owing to higher yield of chickpea in I_2 than that in I_1 (Table 8). Significant difference in the TSP was also recorded among the cropping systems. In 2003-04, the TSP was highest in soybean-chickpea and soybean + maize intercropping-chickpea system followed by maize-chickpea, soybean + pigeonpea intercropping and sole pigeonpea system. However, in 2004-05 and 2005-06, the TSP was lower in soybean-chickpea and soybean + pigeonpea intercropping system while it was higher in systems where maize was a component crop like maize-chickpea, maize + pigeonpea intercropping and soybean + maize intercropping-chickpea system. This was because of lower yield of soybean and at the same time maize yield was considerably better in the last two years of the study. Consequently, the systems involving maize crop, either as sole or intercrop gave higher productivity than other systems under both land treatments. The TSP was higher in maize/ pigeonpea intercropping systems where there was no subsequent chickpea crop. Thus, in places where irrigation water is not available to grow chickpea, maize/ pigeonpea intercropping system will be a preferred system than the sole soybean-chickpea cropping system.

Conclusions

The runoff and soil loss from BBF are less than that from FOG land treatment. Besides this, BBF also

Table 8. Total system productivity as soybean equivalent yield (SEY)

Cropping system	Total system productivity as SEY (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	Mean	2003-04	2004-05	2005-06	Mean
Irrigation								
I_1 - One pre-sowing (PS)	2820b	2750b	3860b	3143b	2260b	2430b	3370b	2687b
I_2 -PS + one irrigation at flowering stage	2930a	2900a	4200a	3343a	2420a	2540a	3590a	2850a
Cropping systems								
Soybean +chickpea	3530a	2110d	3020c	2887c	2700a	1890c	2610c	2400c
Maize +chickpea	2930b	3460a	4510a	3633a	2300b	3040a	3830a	3057a
Soybean/ maize intercropping + chickpea	3390a	2810b	4560a	3587a	2798a	2485b	3933a	3072a
Soybean/ pigeonpea intercropping	2620c	2370c	3530b	2840c	2260b	2030c	2912b	2401c
Maize/pigeonpea intercropping*	1910d	3390a	4510a	3270b	1650c	2980a	4110a	2913a

*There was sole crop of pigeonpea in 2003-04
Figures followed by different letters in a column are different significantly at 5% probability level

helps in safe drainage of excess rainfall and reduces chance of water stagnation in the rainy season crops while it retains higher moisture during the later phase of crop growth after withdrawal of monsoon and produced higher crop yield than the traditional flat land sowing system. The study provides an option for crop diversification from the present predominant soybean based cropping systems to maize-chickpea, soybean/ maize intercropping-chickpea and maize/ pigeonpea intercropping system in the studied watershed *i.e.* cropping systems where maize is a component. Water lost as surface run-off could be conserved in watershed ponds and used as supplemental irrigation which would increase system productivity and maintain soil health by reducing the loss of top soil and nutrients in Vertisols.

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Received 12 September 2011; Received in revised form 7 February 2013; Accepted 23 May 2013