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Land surface modification and crop diversification for enhancing productivity of a Vertisol

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Abstract

Vertisols occur extensively in central India and have high production potentials. Because of the high clay content (40-60% or more), high bulk density (1.5-1.8 Mg m^{-3}) and related properties, these soils have high moisture storage capacity. Conversely, these soils become very hard when dry and very sticky when wet. Since last two decades, scientists, farmers and also the policy makers have been striving to manage these soils through harnessing the beneficial attributes as well as overcoming the production constraints. Some of the potential options are efficient surface land configuration and crop diversification. Field experiments were conducted at the Research Farm at Bhopal to evaluate the land surface configuration and crop diversification. Results of our experiment on vertisols showed a considerable reduction in run off of water and also soil loss from broad-bed and furrow (BBF) compared to flat-on-grade (FOG) during rainy season and at the same time crop productivity was significantly improved in BBF. It enhanced yield of soybean (*Glycine max* (L.) Merr.), maize (*Zea mays* L.), pigeonpea (*Cajanus cajan* (L.) Millsp.) as sole and as well as intercropping and sole chickpea (*Cicer arietinum* L.) by about 12.7-20.0% over FOG. The yield of crops (soybean, maize and pigeonpea), expressed as soybean equivalent yield, was compared and it showed an improvement in yield from different intercropping systems on BBF. The residual effect of rainy season crops on succeeding chickpea was not significant; however, its yield in two irrigation (one pre-sowing plus one post-sowing) was significantly greater than pre-sowing irrigation only in both land configurations. Water use efficiency (WUE) of chickpea was more under BBF than FOG. The study elucidates the constraints and potentials of vertisol for crop production especially with reference to central India and effective ways to improve crop productivity through land surface modification and crop diversification.

Keywords: Vertisols; Crop production; Broad-bed and furrow; Soybean-based system.

Introduction

In India, vertisol soils occupy a total area of 70.3 million ha, constituting 22% of the total geographical area of the country, of which 34.3 and 30.2% are in Maharashtra (western India) and Madhya Pradesh (central India), respectively. Other Indian states having significant areas under this soil are Andhra Pradesh (13.4%), Karnataka (8.0%), Gujarat (7.0%), Tamil Nadu (4.0%), Rajasthan (1.5%) and Uttar Pradesh (1.6%). These soils occur in the locations lying between 8° 45' and 26° 0' N latitude and 66° 0' and 83° 41' E longitude (Murthy et al., 1982). Based on annual rainfall and probability of their occurrence, Vertisol region is sub-divided into two categories-vertisols of dependable rainfall areas and vertisols of undependable rainfall areas (Figure 1, Virmani et al., 1988). The areas under the former category are characterized by a reliability of rainfall occurrence at short intervals and average annual rainfall exceeds 750 mm and is located in the flood plains, valley bottom and plateau; whereas the vertisols of undependable rainfall areas receive annual rainfall of 500-750 mm and are characterized by erratic onset, distribution and withdrawal of rainfall. Moreover, frequency of occurrence of dry spells in these low rainfall areas is very high and a large proportion of the annual rainfall is received in the months of September and October only; these areas are primarily located in the rain shadow region in the states of Maharashtra and Karnataka.

Figure 1. Map of India showing distribution of vertisols soil with dependable and undependable rainfall (Source: Virmani et al., 1988).

The soils have unique feature. Central Indian vertisols are texturally clay loam, silty clay and clays with 39-76% clay, 13-38% silt and 3-41% sand (Virmani et al., 1982). The differences in clay content between the surface and subsurface horizons vary among soils. Upon cracking during dry period, some of the finer particles get detached from the surfaces or sloughed off and fall into the cracks and accumulate in subsoil horizons. The extent of cracking depends on the nature and amount of clay, soil depth, subsoil materials and the length of drying period (Bandyopadhyay et al., 2003). The clod density ranges from 1.5-1.8 Mg m^{-3} (Virmani et al., 1989) and the bulk density is 1.33 in 0-15 cm soil depth to 1.41 Mg m^{-3} in 15-30 cm (Hati et al., 2006). Upon wetting, some clay particles disperse and migrate downward with percolating water and are deposited at the bottom of cracks, or in the pore spaces (Waller and Wallender, 1993). The dominant clay mineral in most of the Vertisols is smectite. These soils become very hard when dry and extremely sticky when wet. Thus, they can only be cultivated and tilled within a limited soil-moisture range. This is a major crop production constraint. The concentration of clay in subsurface horizons may be beneficial or detrimental, depending on the degree of accumulation. To some extent, higher concentration of clay in subsoil layers leads to greater retention of soil moisture as well as nutrients. High accumulation of clay beyond a certain limit leads to the formation of clay pan restricting root penetration and movement of air and water. The swell-shrink potential is so strong that sometimes crop production purposes are not conducive. Apart from soil related constraints, erratic behaviour of monsoon rains and droughts affect crop production with respect to their onset, distribution, intensity and withdrawal. Moreover, appropriate location specific contingency crop planning for these aberrant weather situations is also not available to the farmers, consequently productivity is low. Vertisols of dependable rainfall areas often face problems of internal drainage and are exposed to short-term water logging during the rainy season and crops suffer from adequate root respiration. Vertisols require some specific farm implements to operate within a very narrow range of soil moisture. More traffic in the field leads to compaction of subsoil, thus simultaneous operation of tilling the soil, fertilizer application and seeding is highly desirable to avoid compaction.

Cracking of soil provides extra surface for moisture loss; on the other hand, the crack space assumes significance in that it can accommodate high amount of rainfall facilitating moisture recharge in these otherwise slowly permeable soils (Dasog and Shashidhara, 1993). Cracking during crop growth period damages fine roots of crops. Sometimes the rapid, local, heterogeneous swelling causes water to flow into cracked Vertisol and result in limited bypass flow (Favre et al., 1997). The effect of cracking on crop growth is significant when the slickensided horizon occurs at or within 50 cm. The ill effects of slickensides are reduced when these horizons occur at lower depths, since the root distribution of most annual crops is confined to almost 50 cm depth. The moisture content of the soils, at 33 kPa and at 1500 kPa, ranges from 25 to 47% and 12 to 30% (gravimetric), respectively. The available water capacity (AWC) of these soils ranges from 145 to 380 mm for the upper one-meter depth (Gupta et al., 1991). The moisture characteristics of these soils are steep and available moisture range is low. Most of the moisture movement takes place below 50 kPa soil water suction. Irrigation methods should be so designed to apply water at a rate less than the hydraulic conductivity of the soils. Rainfall events occurring at a rate less than hydraulic conductivity will result in complete absorption of entire amount of rainfall in soil profile. Moreover, lack of application of suitable soil and water management practices by the farmers of the Vertisol region result in soil erosion, reduced water use efficiency and ultimately decrease in productivity. Low hydraulic conductivity in theses soils are due to high clay content, fine pore size and slow internal drainage. The hydraulic conductivity range is very high within a narrow moisture regime. The percolation rates are very high (8.3 mm h^{-1}) and hydraulic conductivity of soil (*in-situ*) at 0-40 cm soil depth is 22.7 cm per day (Mohanty et al., 2004), with low terminal infiltration rate of ~0.2 mm hr^{-1} (Virmani et al., 1989). There is practically no moisture transfer below 40% volumetric moisture content, which is responsible for high water holding capacity of these soils. There is chance of water stagnation, high runoff and soil loss during high intensity rainfall due to low infiltration rate of the profile.

While comparing different sequential cropping it was found that, though the net return from soybean (*Glycine max* (L.) Merr.)-wheat (*Triticum aestivum* L.) is marginally higher than other systems, the soybean-chickpea (*Cicer arietinum* L.) system is more suitable in the central ecological niche of India due to its low requirement for non-renewable energy resources, higher energy use efficiency and benefit-cost ratio (Mandal et al., 2002). Alagarswamy et al. (2000) reported that there was a threshold soil depth (37 cm), below which crop productivity in Vertic Inceptisols could not be sustained, even in good rainfall years. The productivity of single crop like soybean is decreasing recently. For improving its productivity and profitability, there is an urgent need for crop diversification. Further, farmers resort to soybean-chickpea crop rotation whenever there is lack of rainfall during rainy season and irrigation facilities in succeeding winter season. The fallow-chickpea rotation is suitable for extremely poor farmers with no irrigation facilities. The total energy input to the soybean-wheat cropping system is much greater than soybean-chickpea, pigeonpea (*Cajanus cajan* (L.) Millsp.) monocropping, fallow-wheat and fallow-chickpea; and the share of non-renewable to the total energy input is greater than renewable energy inputs in central India (Mandal et al., 2005). But, there is a lack of studies on crop combinations with soybean, although soybean is an excellent crop to fit with other crops. Thus, attempts are made in this paper with the objective to evaluate the land surface modification and crop production performance, crop diversification and intercropping, for increasing productivity of central Indian vertisols.

Materials and Methods

Field experiments were conducted for four years (2003-2007) on an on-station watershed at the experimental farm of the Indian Institute of Soil Science (23° 18′ N, 77° 24′ E, 485 m above mean sea level), Bhopal, Madhya Pradesh, India. The climate was hot sub-humid sub-tropical with hot summers and mild winters. The average annual rainfall was 1083 mm and potential evapotranspiration was 1400 mm. The experimental soil belongs to *Typic Haplustert* of the Vertisols, having deep heavy clay with organic C of 4.8 g kg^{-1}, 112 mg kg^{-1} of available N, 2.6 mg kg^{-1} of available P, 230 mg kg^{-1} of available K, pH 7.7, cation exchange capacity 46 cmol kg^{-1} and bulk density of 1.34 Mg m^{-3}. The water holding capacity at saturation was 62.8%, field capacity 38.9% and permanent wilting point was 24.6% on volume basis.

The experiments were conducted on two land configurations-broad bed and furrow (BBF) and flat on grade (FOG). The BBFs were prepared with a BBF former mounted behind a tractor. The width of each bed and furrow was 1.0 and 0.5 m, respectively; thus the width of one unit of BBF was 1.5 m; and the crops were sown through seed drill on each bed. As a diversified crop, maize and pigeonpea were grown as sole or as intercrop with soybean in the rainy season and chickpea in winter (photo plates 1 to 4). In each land configuration, there was five treatment combinations: sole soybean (*Glycine max* (L.) Merr.)-chickpea (*Cicer arietinum* L.), sole maize (*Zea mays* L.)-

chickpea (*Cicer arietinum* L.), soybean/maize-chickpea, soybean/pigeonpea (*Cajanus cajan* (L.) Millsp.) and maize/pigeonpea intercropping; four rows of sole soybean and two rows of sole maize were grown in each bed for the first two treatments, respectively; for soybean/maize, soybean/ pigeonpea intercropping, four rows of soybean and one row of either maize or pigeonpea were grown in each bed; and 2:1 row ratio was maintained for each bed of maize/pigeonpea intercropping. In place of maize/pigeonpea intercropping, there was pigeonpea sole crop in the year 2003-04.

During winter season, chickpea was grown with two irrigation levels, pre-sowing (I_1) and pre-sowing plus one irrigation at flowering (I_2). The irrigation was provided from the pond where rainwater was harvested during rainy season. Farmyard manure @ 5 t ha^{-1} was applied once in a year during final land preparation before sowing of the crop in rainy season. The applied fertilizer N-P-K rates were 30-25.8-24.9, 120-25.8-33.2, 30: 25.8-33.2, 30:25.8-33.2 kg ha^{-1} for soybean, maize, pigeonpea and chickpea, respectively; sources were urea, single super-phosphate and muriate of potash. For maize, N fertilizer was applied in two splits. Soybean, maize and pigeonpea were sown during the last week of June 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. Crops were harvested manually at their physiological maturity and grain yield was recorded from net plot harvest. Crop yields were expressed as soybean price equivalent yield to have a valid comparison.

The runoff readings were collected from the automatic runoff recorder (Thalimedes) installed at the lowest contour point. Thalimedes was placed on H-flume. 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). For estimation of soil loss, sediment samples were collected from an automatic pumping sediment sampler. The water along with suspended sediments passing through the H-flume was collected in plastic bottles at 20 minute intervals, later soil loss was estimated.

The data were statistically analysed using analysis of variance technique as applicable to split-plot design (Gomez and Gomez, 1984). The mean differences between treatments were compared using the least significant difference (LSD) and the ordering of treatments was done after Duncan's range test at 5% level.

Results and Discussion

Runoff and soil loss

Runoff and soil losses from the field area under broad-bed and furrow (BBF) and flat on grade (FOG) land treatments were monitored during the crop growth period. Total seasonal runoff from BBF plot was less than that from FOG in every year of the study (Table 1). The runoff was 15.4 to 33.2% and 20.3 to 27.7% of seasonal rainfall from BBF and FOG, respectively. This might be attributed to the reduced speed of runoff from BBF due to uniform slope, which have resulted in higher opportunity time for infiltration in BBF than FOG treatment (Acharya and Hati, 2002). The run off from both BBF and FOG was higher during the rainy season of the year 2006 because of unusually very high rainfall. The soil loss through runoff from BBF and FOG were higher in the high rainfall years; the extent of soil was to the tune of 1956 and 2837 kg ha^{-1} from BBF and FOG, respectively in 2003 and 3503 and 6365 kg ha^{-1} in the corresponding treatments in 2006. However, the losses were relatively less in the year 2004. Hence, it has been observed that the BBF system was useful in decreasing run-off and increasing infiltration of rainfall. Singh et al. (1999a) also suggested for a watershed-based farming system to capture significant amount of rainwater lost as run-off and deep drainage. This system also provides great flexibility to fit crops either intercrops or sequence crops with widely differing row-spacing requirements. In a raised and sunken bed (RSB) system, Tomar et al. (1996) also found a considerable reduction in runoff and soil losses and improving crop yield in regions having assured and high rainfall.

Table 1. Seasonal rainfall, runoff and soil loss from different land configuration, broad-bed and furrow (BBF) and flat on grade (FOG); values within parentheses indicate the percent of seasonal rainfall.

Year	Rainfall (mm)	Runoff (mm)		Soil loss (kg ha^{-1})	
		BBF	FOG	BBF	FOG
2003	1058.0	163.0 (15.4%)	214.9 (20.3%)	1956.0	2836.9
2004	798.2	124.0 (15.5%)	183.3 (23.0%)	657.0	1466.0
2005	946.0	177.0 (18.7%)	246.0 (26.1%)	1402.0	3123.0
2006	1513.0	502.0 (33.2%)	873.0 (57.7%)	3503.0	6365.0

Crop growth and yield

The grain yield of soybean in sole soybean varied during the years of experimentation due to differential rainfall and its distribution (Table 2). In the year 2004, the grain yield of soybean was typically low in both BBF and

FOG land treatments because of less rainfall. However, results revealed that the grain yield of soybean in sole soybean, soybean/maize intercropping and soybean/pigeonpea intercropping systems under BBF was greater than that under FOG for every year of the experimentation. On an average over four years, BBF registered 12.7-18.0% greater grain yield of soybean than FOG under sole soybean. In the year 2003-04, the row ratios for both the soybean/maize and soybean/pigeonpea intercropping system were 2:2. Consequently, soybean plant population in intercropping systems was reduced to half compared to sole soybean and thus it was reflected in the yield of this crop. For other years, the row ratios were 4:1 for soybean/ maize (Plate 1) and soybean/pigeonpea; and the soybean yield in sole soybean and soybean/pigeonpea intercropping was similar, but it reduced in soybean/ maize intercropping. The growth of soybean in association with pigeonpea was not affected as pigeonpea was a slow growing crop and the competition between intercrops was less. Soybean crop in soybean/maize intercropping was affected mainly due to competition between the crops for light and nutrients. The higher yield in BBF than FOG was attributed to better growth of the soybean as indicated in leaf area index of the crop. LAI of soybean reached its maximum of 2.45 at 60 DAS in sole soybean under BBF and 2.31 in the same treatment and date of observation under FOG (Figure 2). Among the cropping systems involving soybean, either as sole or intercropping, LAI values were greater in sole soybean than soybean/maize and soybean/pigeonpea intercropping. In soybean/maize intercropping, the LAI of soybean was lowest due to the competition with the maize crop. Okada et al. (1991) also reported that ridge and furrow system made on a vertisol at ICRISAT were better than flat seedbeds both in terms of soil aeration (oxygen concentration) and growth of pigeonpea.

Table 2. Seed yield of soybean as sole and in intercropping systems with maize and pigeonpea on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations.

Cropping system	Seed yield of soybean (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Sole maize	1831	641	1527	1178	1581	543	1337	1029
Soybean/ maize intercropping	646	285	996	780	563	252	967	701
Soybean/ pigeonpea intercropping	735	626	1856	1146	660	516	1581	1025

Plate 1. Soybean-maize intercropping on broad-bed and furrow (BBF) system.

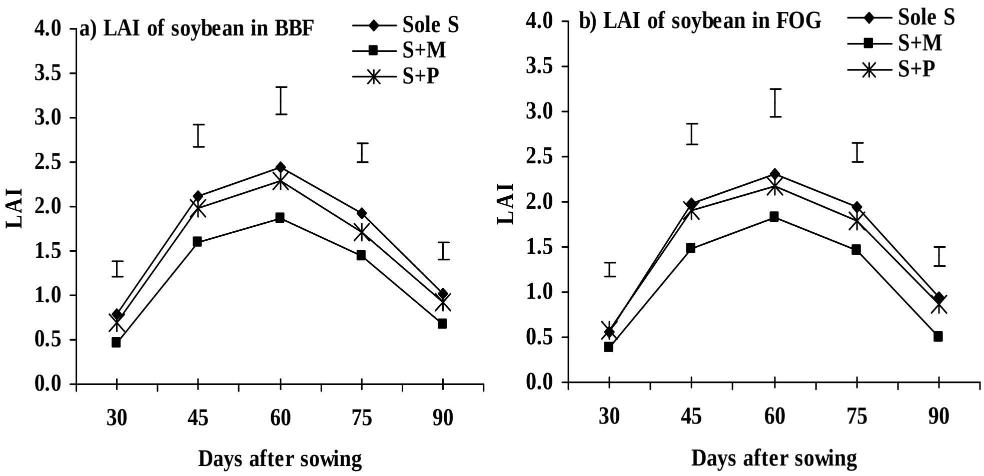

Figure 2. Leaf area index (LAI) of soybean as sole and in association with maize and pigeonpea under (a) broad-bed and furrow and (b) flat on grade; 'sole S' indicates sole soybean, 'S+M' is soybean/maize intercropping and 'S+P' soybean/ pigeonpea intercropping; vertical bars indicate LSD (P<0.05).

Grain yield of maize in sole maize treatment under BBF was 11.8-16.0% greater than the same treatment under FOG (Table 3; Plate 3). In soybean/maize and maize/pigeonpea intercropping systems, grain yield of maize was also greater in BBF than FOG. In 2003-04, though maize population in soybean/maize intercropping was similar to the sole maize, maize yield was reduced in intercropping by 203 and 244 kg ha^{-1} in BBF and FOG, respectively. For other years, maize yield in soybean/ maize intercropping was lower than the sole maize because of reduced plant population, almost half of the sole maize population. In maize/ pigeonpea intercropping, maize population was similar to the sole maize, as pigeonpea was intercropped with maize in the additive series (Plate 2). This trend was observed in every year since 2004-05. Better crop growth in terms of leaf area index (LAI) was observed in BBF. LAI of maize reached its maximum at 2.68 in soybean/maize intercropping under BBF and 2.55 in the same intercropping under FOG (Figure 3); LAI of maize was greater in soybean/ maize than maize/pigeonpea intercropping and sole maize, probably because of the less inter-plant competition across and within crop rows of maize. Again, pigeonpea, due to its slow growth in the early stages, did not compete with the fast growing maize. Thus, LAI of maize in maize/pigeonpea intercropping was also greater than sole maize. The growth of maize in soybean/maize intercropping was better than other treatments, because in this treatment maize was sown with 4:1 (soybean: maize) row ratios and experienced least competition.

Plate 2. Maize-pigeonpea intercropping on broad-bed and furrow (BBF) system.

Table 3. Grain yield of maize as sole and in intercropping systems with soybean and pigeonpea on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations.

Cropping system	Grain yield of maize (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Sole maize	3637	4262	5827	4892	3253	3658	5023	4391
Soybean/ maize intercropping	3434	2249	4140	2901	3009	1938	3361	2611
Maize/ pigeonpea intercropping*	-	4315	5651	4722	-	3709	5375	4401

* During the year 2003-04, there was pigeonpea sole crop in place of maize/pigeonpea intercropping.

Plate 3. Maize crop under maize-chickpea cropping system on broad-bed and furrow (BBF) system.

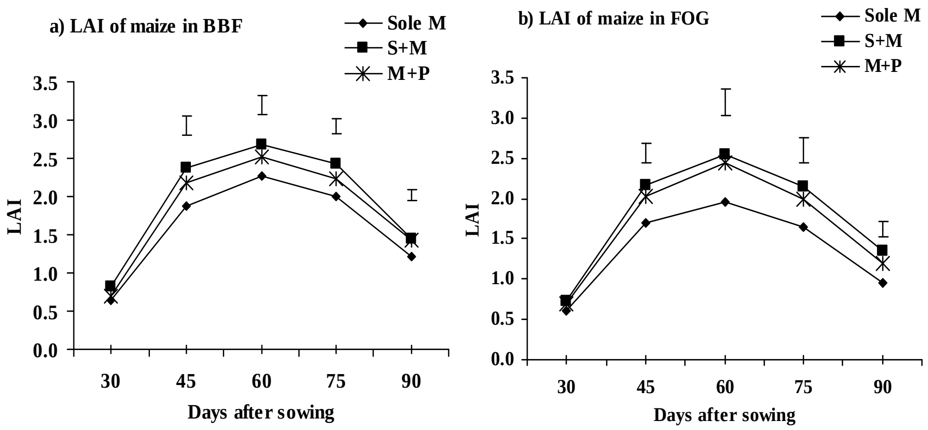

Figure 3. Leaf area index (LAI) of maize as sole and in association with soybean and pigeonpea under (a) broad-bed and furrow and (b) flat on grade; 'sole M' indicates sole maize, 'S+M' is soybean/ maize intercropping and 'M+P' maize/ pigeonpea intercropping; vertical bars indicate LSD ($P<0.05$).

There was sole pigeonpea in place of maize/ pigeonpea intercropping treatment and soybean/ pigeonpea intercropping (2:2 row ratio) in the year 2003-04. In fact there was no difference in soybean/ pigeonpea intercropping and pigeonpea sole crop with respect to plant population because two rows of soybean were sown in between two rows of pigeonpea in the additive series. Thus yield of pigeonpea in these two treatments was almost similar (Table 4). In the subsequent years, i.e. from 2004-05 onwards, pigeonpea was involved in two treatments, i.e. soybean/pigeonpea intercropping (4:1 i.e., 1 row of pigeonpea with 4 rows of soybean) and maize/pigeonpea intercropping (2:1 i.e., 1 row of pigeonpea in between 2 rows of maize). On an average, pigeonpea grain yield was higher in BBF than FOG in both systems. In 2004-05, pigeonpea grain yield was 15.5% higher in BBF than FOG in soybean/ pigeonpea intercropping and 9.8% higher in BBF than FOG in maize/ pigeonpea intercropping. In both the land treatments the yield of pigeonpea was lesser when it was intercropped with maize than with soybean because growth of maize was faster and more competitive that soybean. Studies carried out by Singh et al. (2000) showed that *in-situ* moisture conservation through compartmental bunding on a shallow black soil could increase winter sorghum yield by 25%. In a vertisols of south India, BBF produced 34 and 33% more grain yield of sorghum and pearl millet, respectively, over flat bed in a high rainfall year and compartmental bunding stored 22% more soil moisture and increased the yield of sorghum/ pigeonpea intercropping than did flat bed in a low rainfall year (Selvaraju et al., 1999).

Table 4. Grain yield of pigeonpea in intercropping systems with soybean and maize on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations (*pigeonpea sole crop in the year 2003-04).

Cropping system	Grain yield of pigeonpea (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Soybean/ pigeonpea intercropping	1880	1744	1269	1438	1602	1510	1007	1269
Maize/ pigeonpea intercropping*	1907	1287	1094	1050	1646	1172	904	961

Soybean equivalent yields

Soybean equivalent yield (SEY) of rainy season crops was higher in BBF than FOG (Table 5). In the year 2003-04, SEY of systems were in the order: soybean/pigeonpea intercropping > sole pigeonpea > sole soybean > soybean/ maize intercropping > sole maize both in the BBF and FOG. In the year 2004-05, the order was: maize/pigeonpea intercropping > soybean/ pigeonpea intercropping > sole maize > soybean/maize intercropping > sole soybean and in 2006-07 it was in the order maize/pigeonpea intercropping > soybean/ pigeonpea intercropping > sole maize > soybean/maize intercropping > sole soybean. Similar results were also obtained by Singh et al. (1999b) where total productivity of soybean-chickpea rotation in the BBF was greater than flat configuration in 70% of years.

Grain yield and water use efficiency (WUE) of chickpea

The grain yield of chickpea was greater in BBF than FOG in every year of our experimentation. In both the land configuration, chickpea yield was similar in the three cropping systems (Table 6). Thus, the residual effect of rainy season crops on the performance of succeeding chickpea was not significant, whereas irrigation treatments showed significant variation in the performance of chickpea (Plate 4). The grain yield of chickpea in I_2 (one pre-sowing + one post-sowing irrigation) was significantly greater than I_1 (pre-sowing irrigation) in both the land configuration. WUE of chickpea was more under BBF than FOG (Table 7). In the year 2003-04, WUE in BBF was significantly higher in I_1 than I_2 irrigation treatment but in FOG the difference among the irrigation levels was not significant. Residual effect of the previous crop had not shown any significant effect on the WUE of chickpea in both BBF and FOG land configuration. In the year 2005-06 and 2006-07, WUE was significantly higher in I_2 than that in I_1, probably due to higher increase in seed yield of chickpea compared to corresponding increase in water use with increase in irrigation in BBF; however, in FOG irrigation level has not shown any significantly effect on the WUE of chickpea.

Table 5. Soybean equivalent yield (SEY) of crops (soybean, maize and pigeonpea) on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations (*pigeonpea sole crop in the year 2003-04; values with different letter in a column differ significantly at 5% level according to Duncan's range test).

Cropping system	Soybean equivalent yield (SEY) (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Sole soybean	1831^b	641^e	1527^d	1178^d	1581^b	543^e	1337^c	1029^e
Sole maize	1212^c	2072^c	3163^c	2590^c	1084^c	1778^c	2726^b	2325^c
Soybean/maize intercropping	1791^b	1378^d	3244^c	2315^c	1566^b	1194^d	2791^b	2083^d
Soybean/ pigeonpea intercropping	2615^a	2369^b	3532^b	3134^b	2262^a	2027^b	2912^b	2778^b
Maize/ pigeonpea intercropping*	1907^b	3385^a	4513^a	3951^a	1646^b	2975^a	4112^a	3659^a

Plate 4. Chickpea crop grown under maize-chickpea cropping system with two irrigation on broad-bed and furrow (BBF) system.

Table 6. Grain yield of chickpea as influenced by irrigation levels and cropping systems on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations; I_1, pre-sowing irrigation and I_2, pre-sowing plus one post-sowing irrigation to chickpea at flowering; values with different letter in a column differ significantly at 5% level, according to Duncan's range test.

Cropping system	Grain yield of chickpea (kg ha^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Irrigation levels								
I_1	1893^b	1297^b	795^b	1087^b	1259^b	1202^b	715^b	936^b
I_2	2116^a	1557^a	1203^a	1500^a	1588^a	1397^a	980^a	1423^a
Cropping systems								
Soybean-chickpea	2040^a	1468^a	1076^a	1326^a	1340^a	1349^a	920^a	1181^a
Maize-chickpea	2062^a	1385^a	969^a	1254^a	1453^a	1258^a	797^a	1162^a
Soybean/ maize intercropping -chickpea	1913^a	1429^a	952^a	1301^a	1478^a	1292^a	824^a	1195^a

Table 7. Water use efficiency (WUE) of chickpea as influenced by irrigation levels and cropping systems on broad-bed and furrow (BBF) and flat on grade (FOG) land configurations; I_1, pre-sowing irrigation and I_2, pre-sowing plus one post-sowing irrigation to chickpea at flowering; values with different letter in a column differ significantly at 5% level, according to Duncan's range test.

Irrigation/ Cropping system	WUE (kg ha^{-1} mm^{-1})							
	BBF				FOG			
	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2006-07
Irrigation levels								
I_1	12.38^a	9.13^a	5.05^b	6.75^b	8.72^a	8.97^a	4.74^a	6.46^b
I_2	10.37^b	8.00^b	6.06^a	7.66^a	8.58^a	7.65^b	4.83^a	7.81^a
Cropping systems								
Soybean-chickpea	11.56^a	8.64^a	5.73^a	7.32^a	8.18^a	8.44^a	5.13^a	7.15^a
Maize-chickpea	11.63^a	8.40^a	5.41^a	7.06^a	8.88^a	8.08^a	4.52^a	7.20^a
Soybean/ maize intercropping -chickpea	10.92^a	8.66^a	5.53^a	7.24^a	8.87^a	8.40^a	4.71^a	7.06^a

Conclusion

The study elucidated the distribution of vertisol soils in Indian subcontinent; elucidated the soil characteristics, constraints related to crop production and harnessing potential for successful crop cultivation and soil management. We have listed some viable options for land management issues which might be useful for vertisols and associated soils for rainwater management and sustainable crop production. Our experimental study indicated the agronomic approaches for land surface modification for reduction of runoff of water and soil loss in one hand and enhancing crop productivity on the other. It has also been demonstrated that appropriate crop combination (s) would enhance the crop growth and yield.

Broad-bed and furrow land configuration was better than flat-on-grade land management system for accruing the benefits of better crop yield of soybean, maize, pigeonpea and chickpea on an on-station watershed. The harvesting of rain water in the pond would be useful in providing irrigation to crops, especially for a second crop like chickpea and also for better yield. The study provides the options for different crop combinations under improved land configuration as: maize-chickpea, soybean/ maize intercropping-chickpea and maize/ pigeonpea intercropping. Thus, it would suggest for improved cropping systems involving maize crop, either as sole or intercrop would be appropriate for enhancing productivity. Even this study would suggest for maize/ pigeonpea intercropping system instead of sole soybean. So, farmers would adopt the crop combinations as per the convenience and would increase the overall crop productivity, more specifically, it was concluded that the systems viz. maize-chickpea, soybean/ maize intercropping-chickpea and maize/ pigeonpea intercropping on broad-bed and furrow system would hold the promise for increasing productivity in vertisol soils.

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