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A Modified Contour Bunding System for Alfisols of the Semi-Arid Tropics*

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ABSTRACT

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Contour bunding is the most widely practised soil conservation measure on Alfisols of the semi-arid tropics in India. The conventional contour bund system allows water to stagnate for long periods in extensive areas along the bunds that affects crop yields in these areas. Crop yields from sorghum/pigeon pea intercrop and pearl millet/pigeon pea intercrop at different distances from the bunds were measured to demonstrate the effects of bunding. The effects of eroded sediment deposition on the infiltration behavior of the zone near the bunds are also discussed. A modified contour bunding system with gated outlets is described. Contour bunds with gated outlets were found to ensure adequate control of runoff and soil loss. Crops grown in the fields bunded by gated outlets yielded better than those grown in fields surrounded by conventional bunds. The water balance of the ponded areas near the bunds is presented for both the modified and conventional contour bunding systems.

INTRODUCTION

Alfisols are the third most important soil order in the world, covering about 13% of the land area (Buringh, 1982). They are also the most abundant soils in the semi-arid tropics (SAT), and cover nearly 33% of the region (Kampen and Burford, 1980). Drought is one of the major factors limiting crop production in the SAT Alfisols because these soils have a low water-holding capacity (high sand content >75%, low organic matter <2%, and low smectite content), rainfall is unreliable, and evapotranspiration is high during the crop growing season. The problems of low water-holding capacity and unreliable rainfall are often accompanied by low infiltration rates resulting from soil

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crusting and hard setting, which restrict water entry and reduce the amount of water stored. High rates of runoff and steep slopes lead to severe soil erosion. In addition to reducing water-holding capacity, the latter also depletes the soil of the essential nutrients necessary for plant growth.

In India, nearly 80% of the Alfisols are considered to require some type of conservation measure because they are very prone to erosion (Hegde et al., 1987). Contour bunding is the most commonly used technique. Since 1947, contour bunds have been constructed on about 21 million hectares of agricultural land at a cost of about US$20/ha; this figure constitutes 90% of the total expenditure on soil conservation on agricultural lands in India (Bali, 1980). However, contour bunding is not always successful. Prolonged water stagnation near the bunds usually damages crops and prohibits timely cultural operations. Loss of productive land and frequent breaking of bunds have also been reported from some areas, particularly those on clay soils (Gupta et al., 1971; ICRISAT, 1975/76; Bali, 1980).

Conventional contour bunding involves the construction of small bunds across the slope of the land along a contour so that the long slope is reduced to a series of small ones. Each contour bund is provided with an elevated spillway at the lower end of the field. Each contour bund acts as a barrier to the flow of water down a hillside and thus increases the time water concentrates in an area, thereby allowing more water to be absorbed into the soil profile. The conventional design allows a considerable volume of runoff to be impounded near the bund. This paper examines the problems of conventional contour bunding and discusses a modified system with gated outlets that has been successfully tried at ICRISAT Center.

EXPERIMENTAL CONDITIONS

Climate

The mean annual rainfall (1976–1987) at ICRISAT Center is 748 mm, with 86% falling from June to October, characterized by high-intensity storms. During the period of this study, rainfall varied from 1072 mm in 1981 to 519 mm in 1984. The dates and distribution of rains within the season also varied widely.

A feature of the climate at this location is the high annual potential evaporation, the highest rates occurring in the hot months prior to the rainy season; maximum daily open pan evaporation in May was 19.5 mm in 1980 and 1981. In the rainy season, evaporation may be as low as 1 mm, but rises to 8 to 10 mm on clear days.

Soil

Alfisols within the experimental farm of ICRISAT Center are reddish brown, derived from pink granites, and belong to the isohyperthermic family of Udic

TABLE 1

Physical properties of an Alfisol (Udic Rhodustalf) at the experimental site, ICRISAT Center

Depth (cm)	Particle size distribution (%)			Coarse fragments >2 mm (% of whole)	Bulk density (Mg/m³)	Gravimetric water content (%)	
	Clay	Silt	Sand			1/3 bar	15 bar
0–12	16.0	11.8	72.2	4	1.52	9.2	5.7
12–29	40.2	9.7	50.1	4	1.68	20.0	13.7
29–59	41.1	9.3	49.6	19	1.49	25.2	13.9
56–81	37.1	10.2	52.7	18	1.55	21.4	11.0

Rhodustalfs (Soil Survey Staff, 1975). They are medium-deep, well-drained, sandy loam to sandy clay loam at the surface, occurring on nearly flat to gently sloping uplands. They have a 5–12 cm thick Ap layer underlain by a compact argillic horizon. The dominant clay mineral is kaolinite with varying but small proportions of 2:1 clay minerals and sesquioxides. The soils may contain well-defined gravel and weathered rock fragments at lower depths. They are unstable in structure, slake when wet, compact when dry, and have inherently low water-retention characteristics. Selected physical properties of Alfisols at ICRISAT Center are given in Table 1.

Land management treatments

In 1978, three land management treatments, namely broadbed and furrow, conventional contour bunds, and contour cultivation with field bunds were compared in a four-replicate trial. Twelve small watersheds, each of about 0.6 ha, were constructed. Each watershed was treated with one of the land management systems. Agronomic management of all the watersheds was identical during the experiment and included improved farming methods. Intercrops of pearl millet or sorghum with pigeon pea, and sole crops of castor or pearl millet, were grown in different years in accordance with the recommended rotation. Crop yield was determined from samples (sample size 8×6 m^2) taken at various distances from the bunds in the case of the two contour bund systems and randomly in the other land management systems. Rainfall was measured by two nonrecording rain gauges. Runoff was measured with flumes attached to stage-level recorders. Runoff samples were collected during each storm to estimate soil loss.

At the end of 3 years of experimentation, the performance of various land management treatments were evaluated. It was observed that, even though the conventional contour bund system was most efficient in controlling runoff and

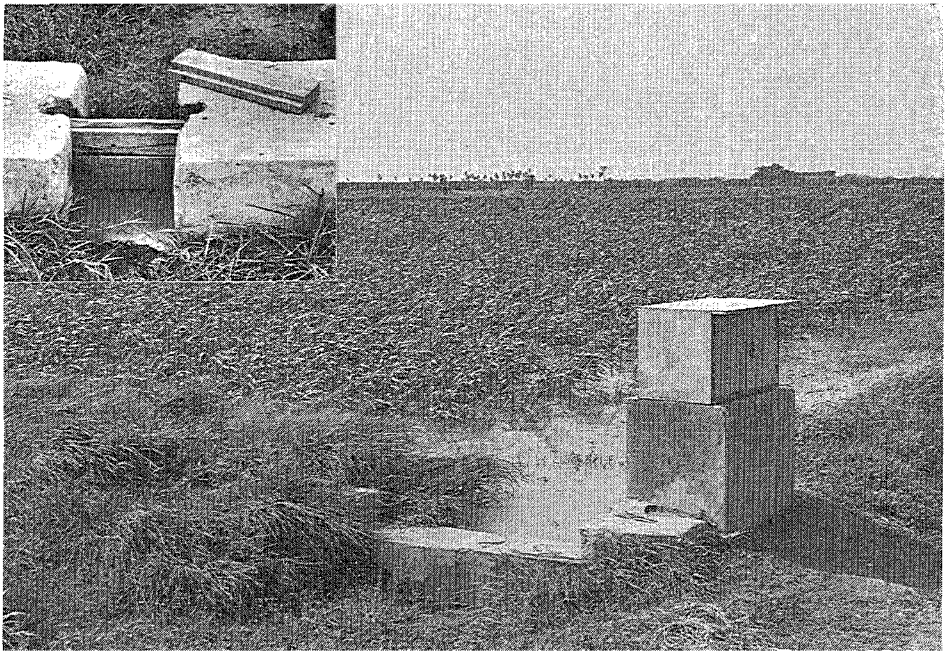

Fig. 1. Contour bund with gated-outlet (inset) system on an Alfisol at ICRISAT Center.

soil loss, it had a major defect of reducing yield because of long periods of water stagnation in the vicinity of the bund.

In 1981, efforts were made to refine the design of the contour bunding system to increase crop yields. From the 4 watersheds under the conventional contour bunds, two watershed bund outlets were modified by installing gated outlets in the lower section of the field (Fig. 1). This allowed runoff to be stored in the field for a desired period, then released at a predetermined rate through the spillway, thus reducing the time the field was waterlogged. Consequently, from 1981/82 to 1984/85 four land management systems, viz. broadbed and furrows, conventional contour bunds, gated-outlet contour bunds and contour cultivation with field bunds were compared.

Field infiltration studies

Water stagnation and the resultant deposition of eroded sediments (which influence infiltration behavior) varies considerably with the distance from the bunds. The infiltration behavior of the soil was measured by using a double-ring infiltrometer at four distances, 2.5, 5.0, 12.5 and 17.5 m, from each bund in the first, fourth and sixth year after the contour bunds were constructed.

The inner infiltrometer ring was 0.3 m in diameter and was driven into the soil to a depth of 0.2 m.

Water balance of the ponded zone

The water balance of the periodically ponded area near two contour bunds was monitored from 1981/82 to 1983/84. Two water-level recorders located near the spillway registered the fluctuations of the level of the ponded water. Evaporation from the ponded water was measured with an evaporation pan located in the ponded area. An accurate topographic survey of the area allowed the relation between water level and volume of water stored behind the bund to be determined.

RESULTS AND DISCUSSION

Crop yields

Between two conventional contour bunds, six distinct zones can be distinguished (Fig. 2a). The differential effects of conventional contour bunds on the grain yields of sorghum/pigeon pea intercrops, grown in 1978/79 and 1983/84 are shown in Figs. 2b and 2c. The grain yields of both crops were lower near the contour bunds. The yield reduction was not only restricted to the upstream region of the inundated area, but also included the seepage zone downstream of the bund. Generally, a 5 m wide strip that included the bund and its borrow pit produced virtually no crop due to lack of topsoil (used for bund construction) and prolonged water stagnation. The latter resulted in very poor crop stands and heavy weed growth. The 1978/79 rainy season was characterized by frequent storms and heavy runoff. The average yield of the entire field in that year, compared to the yield of the unaffected parts, showed a reduction of 11% for sorghum and 17% for pigeon pea. There was high rainfall in 1978/79 and 1983/84, and runoff behavior was similar in those seasons. It was expected that in these two seasons the reduction in yields from the areas near the bunds would be similar. However, yield reduction in 1983/84 was greater than in 1978/79. This was mainly due to the relatively poor infiltration in the ponded area in 1983/84 (the 6th year after construction), as compared to 1978/79 (the year of construction), due to soil pores becoming blocked by deposits of finer materials from stagnant water in previous years.

The comparative performance of conventional contour bunds and contour bunds with gated outlets during the high rainfall season 1983/84 is shown in Fig. 3. A sorghum/pigeon pea intercrop grown in fields with gated-outlet contour bunds yielded 19% more sorghum and 28% more pigeon pea than in fields with conventional contour bunds. Crop yields near the bunds of the gated-outlet system were distinctly higher than those grown under the conventional

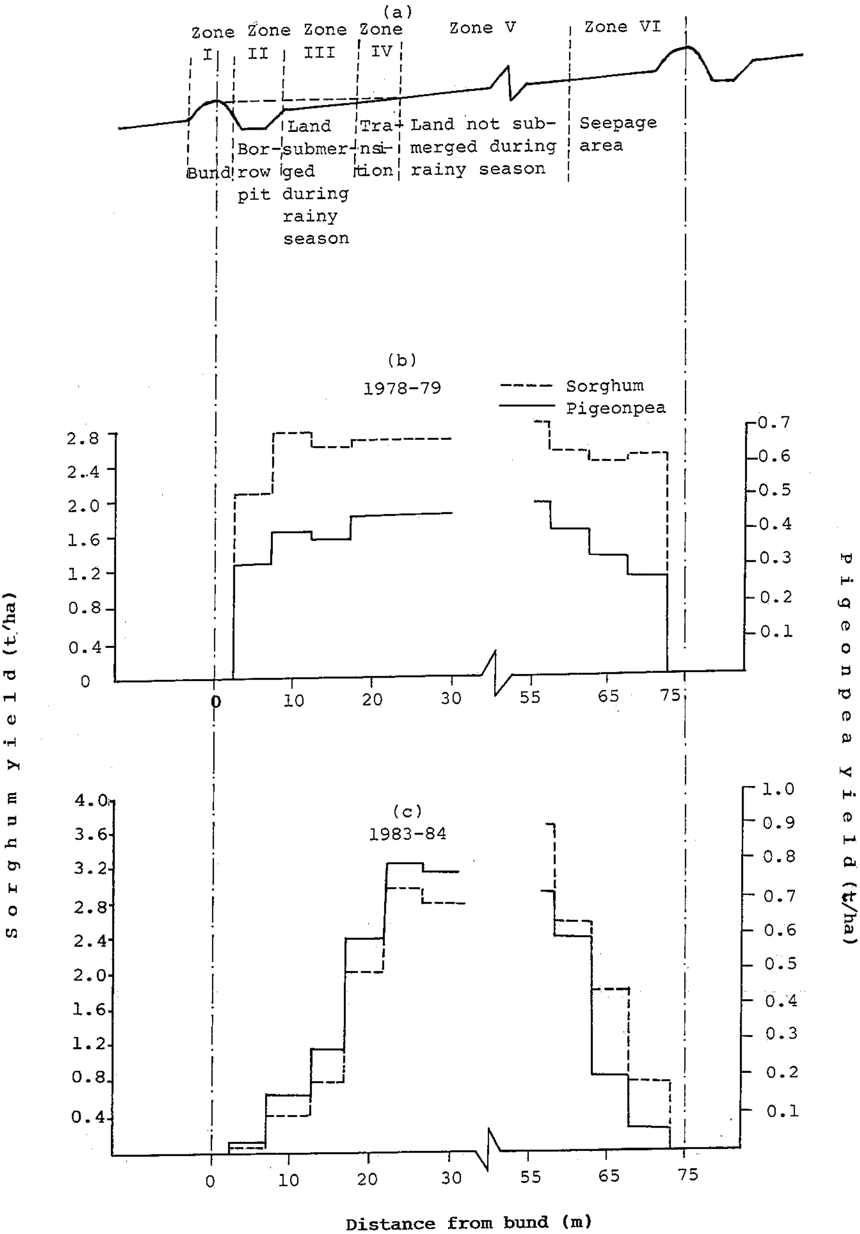

Fig. 2. (a) Cross-section of a conventional contour bunded field. (b) Yield of sorghum/pigeon pea intercrop as a function of distance from the bunds in a conventional contour bunded field in the first year after construction on an Alfisol, ICRISAT Center (Huibers, 1985). (c) Yield of sorghum/pigeon pea intercrop as a function of distance from the bunds in a conventional contour bunded field in the sixth year after construction on an Alfisol, ICRISAT Center.

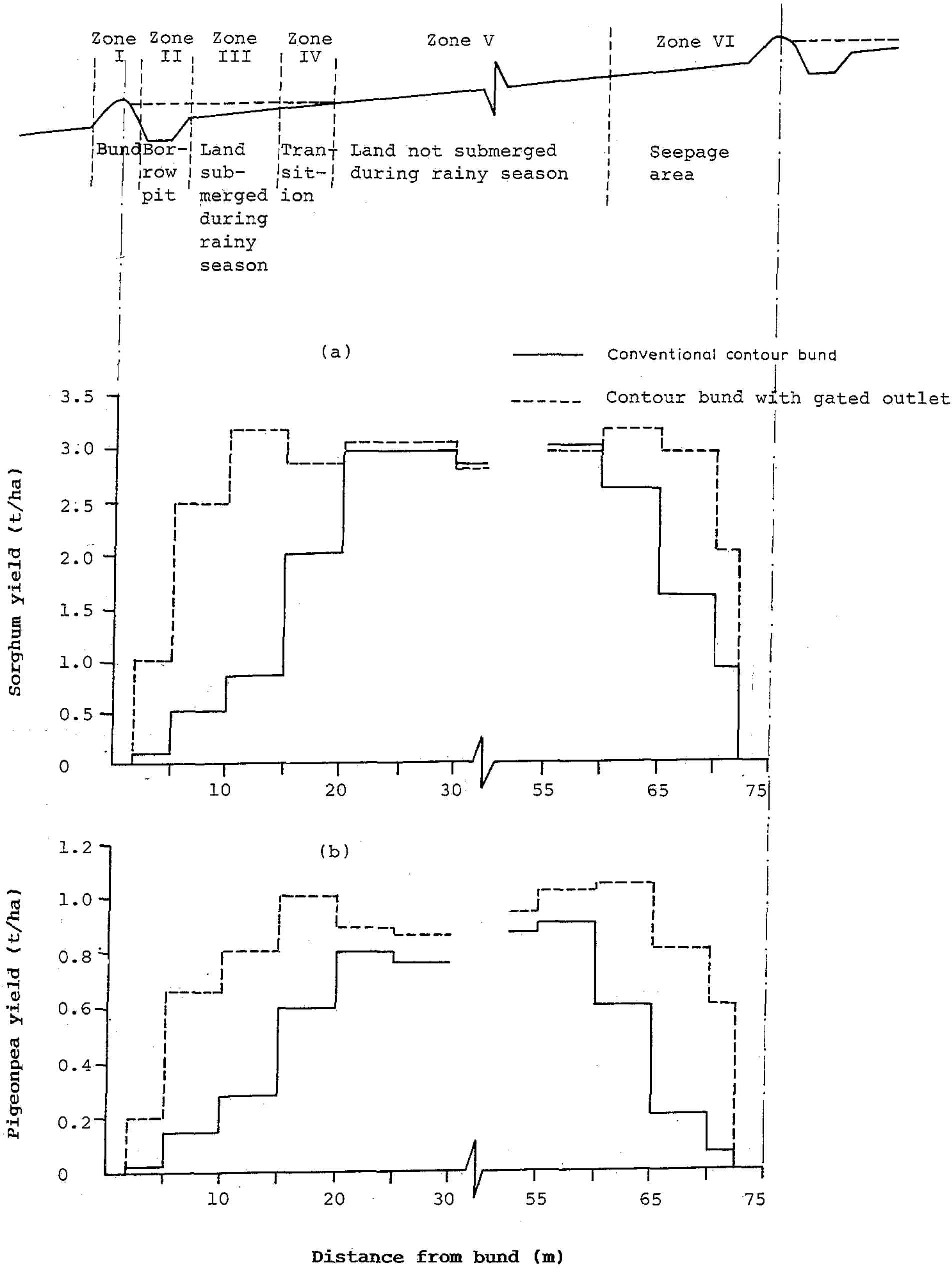

Fig. 3. Comparison of conventional and gated-outlet contour bund systems on yields in a sorghum/pigeon pea intercrop on an Alfisol at ICRISAT Center, 1983/84. (a) Sorghum yield as a function of distance from bund. (b) Pigeon pea yield as a function of distance from bund.

TABLE 2

Grain yield, runoff, and soil loss from different land management systems on Alfisol watersheds at ICRISAT Center over 4 years (1981/82–84/85)

Land management systems[a]	Crop	Grain yield (kg/ha)	Runoff (mm)	Soil loss (t/ha)
(1) Broadbed and furrow	Sorghum/ pigeon pea	2740 880	289	3.61
	Pearl millet/ pigeon pea	2400 920		
(2) Conventional contour bund	Sorghum/ pigeon pea	2520 710	75	0.97
	Pearl millet/ pigeon pea	2230 730		
(3) Modified contour bund gated-outlet	Sorghum/ pigeon pea	3020 970	160	0.92
	Pearl millet/ pigeon pea	2730 1010		
(4) Contour cultivation with field bunds	Sorghum/ pigeon pea	2810 910	215	3.35
	Pearl millet/ pigeon pea	2510 920		

All the treatments with recommended crop management practices, i.e. use of improved cultivars, cropping system, chemical fertilizer, and other practices for weed, pest and insect control (Pathak et al., 1986).

system. This increase in yield was not only restricted to the upstream area where water would otherwise stagnate, but was also in the seepage zone downstream of the bund. Even in low rainfall years (1982 and 1984) higher crop yields were obtained with this system than with the conventional contour bunds.

The comparisons of gated-outlet contour bunds with the other three alternative land management systems is shown in Table 2. The conventional contour bunds and gated-outlet contour bunds were found to be most effective in controlling runoff and soil loss. However, only contour bunds with gated outlets were found to be more effective in increasing yields. On average (mean values of 1981–1984) this system produced highest crop yields and provided adequate control of runoff and soil loss.

Cumulative water infiltration

In both the conventional and gated-outlet contour bund systems, sediments derived from eroded soil were deposited near the bund where water stagnated periodically. These sediments were enriched with finer soil materials (clay and silt) that decreased the infiltration in the submerged area. This is shown in Fig. 4 as a plot of the cumulative infiltration versus time for the conventional bunding system. As the period after bund construction increased, cumulative infiltration in the periodically ponded zone near the bund decreased. For example, cumulative infiltration at 2.5 m from the bund in the conventional system was reduced by 26% in the 4th and 31% in the 6th year after construction. Similar trends were obtained for the gated-outlet system. This implies that in

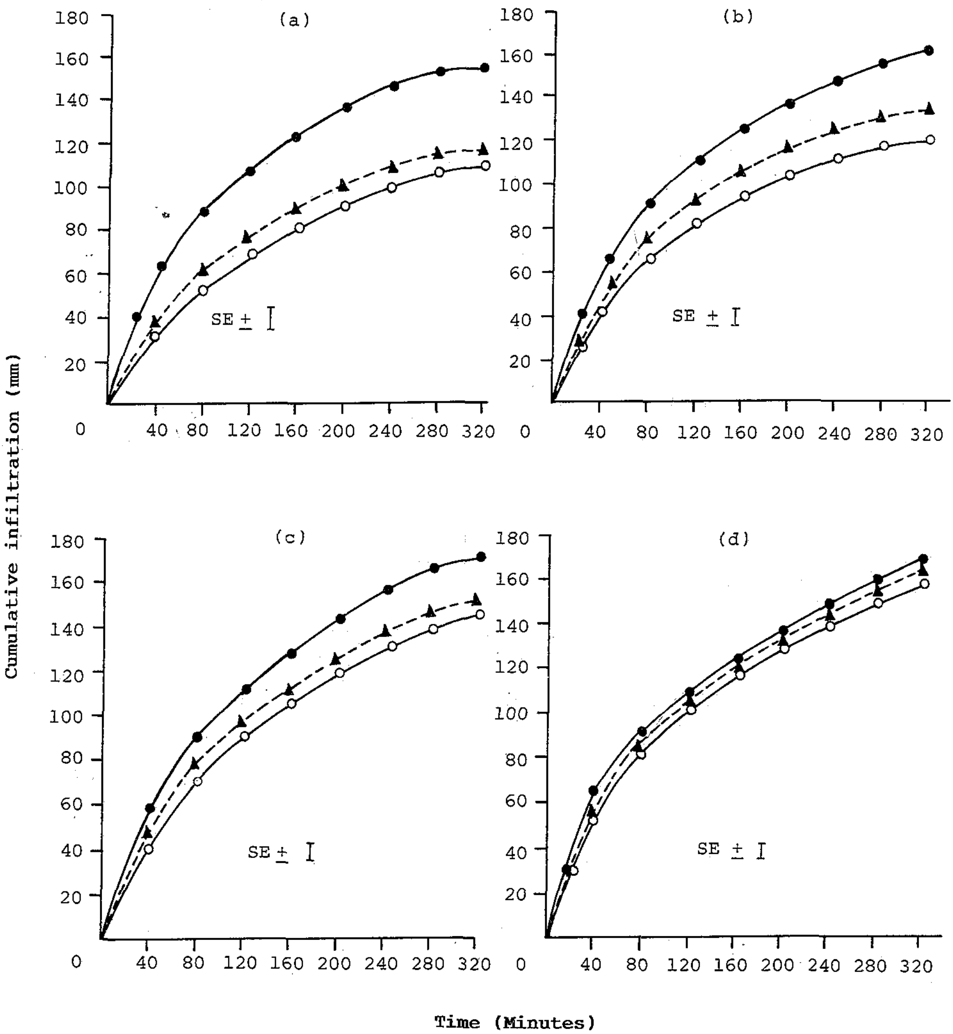

Fig. 4. Effect of conventional contour bund on cumulative infiltration of water on an Alfisol at ICRISAT Center, 1978-1983. (a) 2.5 m from bund, (b) 7.5 m from bund, (c) 12.5 m from bund, and (d) 17.5 m from bund. (●) 1978; first year after construction of bund. (▲) 1981; fourth year after construction of bund. (○) 1983; sixth year after construction of bund.

subsequent years there would be long periods of water stagnation near the bunds in the conventional system. However, in the case of gated-outlet contour bunds, their performance will not be very much affected by this reduction in infiltration since in this system excess water will be released by opening the gates. The cumulative infiltration of water in the zones further away from the bund did not decline over time in either system because few or no eroded sediments were deposited.

Water balance of the ponded area

The maximum amount of water held by each bund in the catchment was 19 mm with conventional contour bunds. Excess runoff only escaped through the

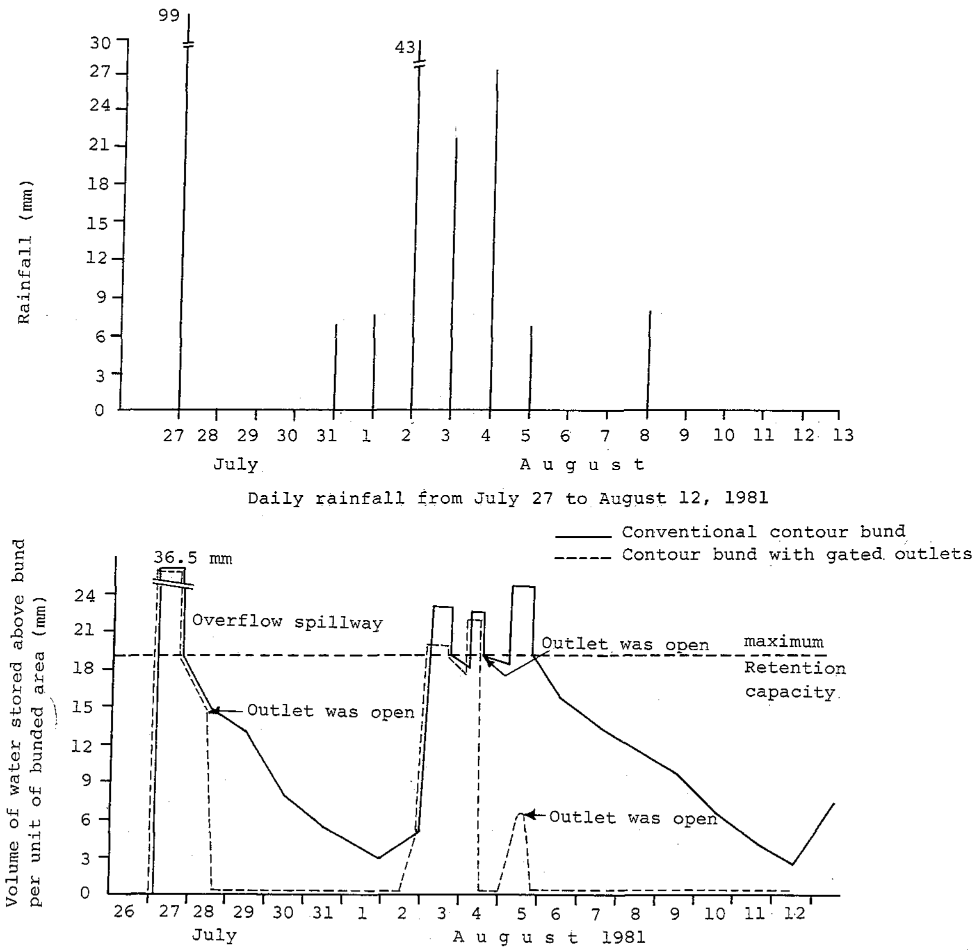

Fig. 5. Water balance in the zone controlled by conventional contour bund and a gated-outlet contour bund system on an Alfisol at ICRISAT Center.

TABLE 3

Water balance of watersheds with conventional and gated-outlet contour bunds at ICRISAT Center over 3 years (1981/82–1983/84) (All values given in mm.)

Year	Rainfall	Conventional contour bunds				Gated-outlet contour bunds			
		Surface water held by bund	Runoff [a]	Water infiltrated in ponded area	Evaporation from ponded area	Surface water held temporally by bund	Runoff [a]	Water infiltrated in ponded area	Evaporation from ponded area
1981/82	1108	98	130	79	19	140	194	36	6
1982/83	769	80	45	68	12	83	50	66	7
1983/84	988	121	96	96	25	161	179	40	5

[a] Amount of spillway outflow.

spillway. Of the 1108 mm total seasonal rainfall in 1981, 228 mm was recorded as excess surface water which could have escaped as runoff from the field. In the conventional system, 98 mm, or an additional 9%, of the seasonal rainfall was stored within the upstream zone of the bunded field. Most of this water (81%) had infiltrated, and only 19% was lost by evaporation. In the gated-outlet system, 140 mm, or an additional 13% of the seasonal rainfall, remained behind the bund. However, most of this water was stored for only short periods and then slowly released by opening the gated outlet. The water balance near two bunds (one for each system) during the period 27 July to 12 August is shown in Fig. 5. Water stagnation near the bund was visible for 16 days (27 July to 12 August; solid lines) in the conventional system. In the gated-outlet system the periods of water stagnation near the bund were short (27 to 28 July, 2 to 4 August) because excess water was released through the outlets. The various water-balance components for conventional and gated-outlet contour bunded watersheds over 3 years (1981/82–1983/84) is shown in Table 3. In the low-rainfall year 1982/83 the runoff from conventional and gated-outlet systems was similar. However, in high-rainfall years 1981/82 and 1983/84 the runoff values were higher in the gated-outlet system, mainly because the excess water (undesirable for crop growth) was allowed to flow as runoff.

CONCLUSION

Well-designed and maintained conventional contour bunds on SAT Alfisols undoubtedly conserve soil and for this purpose contour bunds are perhaps efficient. However, it appears that the associated disadvantages – mainly water stagnation and the absence of crop drainage (particularly during the rainy season) causing reduction in crop yields – outweigh any advantage from the viewpoint of soil conservation. Water stagnation in conventional contour bunds increases over the years as more fine particles are deposited around the bunds. In most years crop yields are greatly reduced in the areas around the bund. On SAT Alfisols, the contour bunds with gated outlets appear to have good promise. Some of its advantages over the conventional contour bunds are:

(1) The problem of prolonged water stagnation around the contour bund is reduced in the gated-outlet contour bund system. This results in higher crop yields particularly in areas near the bunds.

(2) The chances of bund breaching are less in the gated-outlet contour bund system because of less prolonged water-ponding. In conventional contour bunds the occasional breaching of a bund is quite common mainly because of prolonged water-ponding (as many as 40–50 days of continuous water-ponding).

(3) The peak runoff rates are generally less in gated-outlet contour bunds when compared to conventional contour bunds.

(4) Relatively more timely tillage and other cultural operations are possible in

the gated-outlet contour bund system because of better control on ponded runoff water. In conventional contour bunds, timely operations are often not possible because of the prolonged water-ponding situation.

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