Soil Use and Management, June 2008, **24,** 171–180 doi: 10.1111/j.1475-2743.2008.00152.x

An evaluation of furrows for managing soil and water loss from a shallow Alfisol under simulated rainfall

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Abstract

Furrows are widely used in rainfed areas of semi-arid India for soil and water conservation. The orientation of furrows, either down or across slope, and their spacing influence the effectiveness of furrows as soil and water conservation measures. We evaluated treatments with furrows aligned down and across 3% sloping land at spacings of 90, 60 and 30 cm under simulated rainfall intensities of 80 and 100 mm/h on a shallow Alfisol. A bare plot without any furrows was considered as a control. A large (24 m × 3 m) rainfall simulator developed at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, was used for this controlled study. Run-off was measured by a calibrated tipping bucket run-off recorder. The effects of the treatments on peak flow rate (L/s), sediment loss with run-off water (kg/ha/mm), peak sediment concentration (g/L), run-off (per cent rainfall) and time to peak (min) were investigated. When compared with the control (no furrows), across slope furrowing with 60- and 30-cm spacing reduced sediment yields by 19.9 and 21.3 kg/ha/mm of run-off, respectively, under a rainfall intensity of 80 mm/h and 24 and 25.3 kg/ha/mm of run-off, respectively, under a rainfall intensity of 100 mm/h. For the control, sediment loss was 50.72 kg/ha/mm run-off and 56.68 kg/ha/mm run-off for rainfall intensities of 80 and 100 mm/h, respectively. Similar trends were recorded from observations of peak flow, time to peak and peak sediment concentration. Run-off hydrographs demonstrated the conservation value of across slope furrowing by delaying run-off initiation, reducing run-off and slowly releasing the run-off after the cessation of rainfall. The results show that furrow orientation has major effects on reducing run-off, whereas furrow spacing has insignificant effects.

Keywords: Alfisol, furrowing, rainfall simulator, soil and water conservation, sediment concentration, tipping bucket run-off recorder

Introduction

Alfisols are the third most important soil order covering 1.13% of the world (Buringh, 1982). In the semi-arid tropics, these soils constitute about 33% of the land area (Kampen & Burford, 1980). In India, Alfisols occupy about 20% of the rainfed regions covering 59.6×10^6 ha and are located mostly in south India (Venkateswarlu, 1987; Singh, 1995). These soils are shallow, coarse in texture, contain little organic matter and are prone to severe erosion. Crop yields are low partly as a result of the dry climate and partly because the soils are shallow (Littleboy *et al.*, 1996). The soils are often subjected to high-intensity rain storms of short duration causing excessive run-off. On these soils, as much as 25% of the annual rainfall can be expected as run-off (Kanwar, 1982).

Various land management practices are recommended for reducing run-off and soil erosion, but hydrological responses cannot be precisely quantified. Furrows can be oriented either down or across the slope. The most commonly advocated simple conservation measure is the opening of furrows across the slope during cultivation. Many farmers are in the habit of ploughing up and down the slope which is one of the causes of erosion. An experiment at Woburn, England, recorded the reduction in run-off and soil loss and the corresponding increase in crop yields on across slope cultivated plots (Quinton & Catt, 2004). Cultivation along contours

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Received July 2007; accepted after revision March 2008
Editor: Donald Davidson

caused a reduction of 15.6% in run-off and a 15.4% soil loss when compared with cultivation up and down the slope on Alfisols under sorghum in India (Kabango *et al.*, 2000). Rainfall simulation experiments suggest that ridges and furrows across the slope could conserve 50–60% run-off in semi-arid agricultural lands in India (Mishra *et al.*, 2006). For contour cultivation, the mean erosion rates from a plot in China were 31% less than that for down slope planting (Barton *et al.*, 2004). Run-off and soil loss from cultivated plots in the Western Himalaya were reduced by 27 and 45% by contour cultivation of maize (Narain *et al.*, 1998). Summer ploughing/off-season tillage in the rainfed arable land before the onset of the monsoon is common for growing seasonal crops. Lack of vegetation during summer leads to excessive erosion in fields with tillage down the slope. This highlights the need for a study using a rainfall simulator without crops to quantify the conservation benefits of across slope furrowing compared with down slope furrowing under varied rainfall intensities. Furrow spacing depends on crop geometry and is an additional factor controlling soil loss (Mutchler & Greer, 1980). Hence, the relationships between rainfall intensity, furrow orientation and spacing require investigation. Results on soil infiltration, run-off and sediment yield from a shallow soil with varied stone cover and intensity of rainfall have been reported using a small twin-plot rainfall simulator on a plot size of 1.5 m^2 (Mandal *et al.*, 2005). A larger simulator (24 m × 3 m) as used in the present study undoubtedly improves data quality and representativeness of the experimental plots to field conditions. Simulation experiments are more rapid, efficient, controlled and flexible than experiments dependent upon natural rainfall (Meyer, 1994).

Materials and methods

CRIDA rainfall simulator

The rainfall simulator (Figure 1) was designed and developed at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India (Mishra *et al.*, 2003). The width of the simulator is 3.0 m and length is 24.0 m to cover a large run-off plot (2.75 m × 24 m). The simulator consists of an A-framed steel structure assembly with an oscillating mechanism having eight standard spraying type 80100 V-jet nozzles. These nozzles have been standardized for rainfall simulation to produce acceptable results for erosion studies (Young & Burwell, 1972; Foster *et al.*, 1982). The oscillating angle of the nozzle with a cam arrangement is kept at 60° to the horizontal and the nozzles are spaced 3 m apart to achieve uniformity in rainfall application by each nozzle over an area of 3 × 3 m. The nozzles are placed 3 m high for raindrops to achieve terminal velocity. The spray coverage for each nozzle along the length of the plot is 3.2 m with 0.1 m overlap on both sides of the nozzle at 1.0 bar pressure. Each nozzle is connected to a reinforced pipe fitted to a pressure gauge through a gate valve for regulating and maintaining the pressure of flow of water through the nozzle (Figure 2). The nozzles are fixed to a steel bar running along the length of the plot and oscillate across the length of the run-off plot by an electric motor with a cam arrangement. All the nozzles are connected to the water source via a distributor and flexible hosepipes. Water is pumped to all the nozzles by a centrifugal pump drawing water from a sump of 10 m^3 capacity through a non-return valve. Around the run-off plot, a brick masonry wall of height 45 cm (30 cm below ground and 15 cm above), demarcates the experimental area

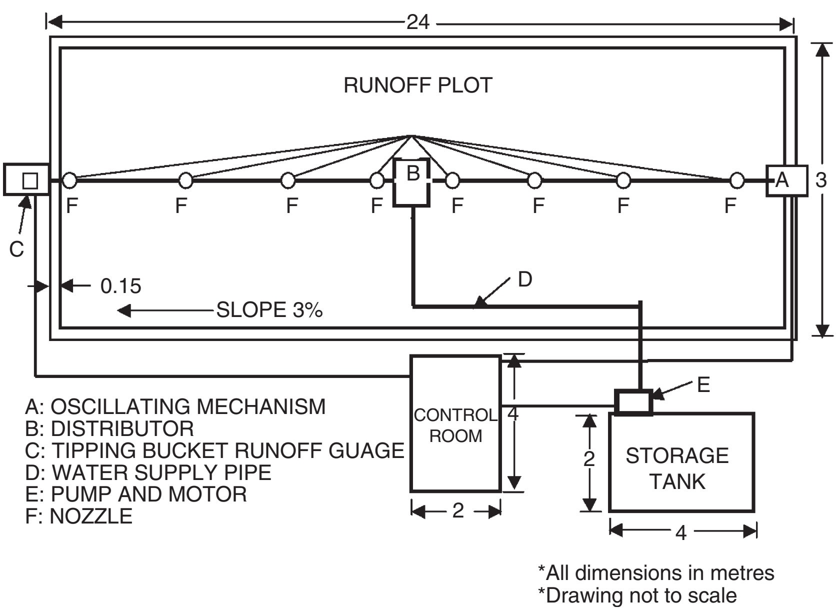

Figure 1 Line diagram of the rainfall simulator.

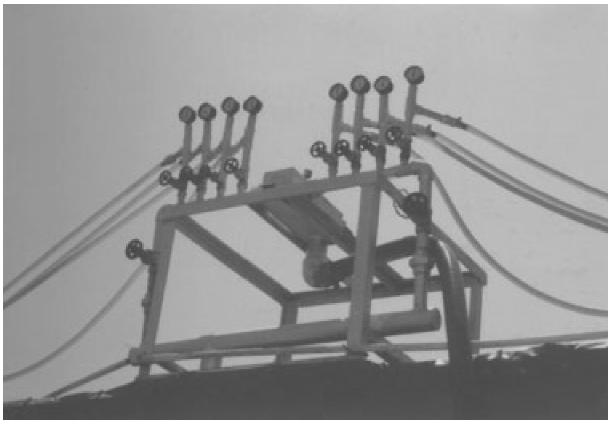

Figure 2 Distribution mechanisms with pressure gauge for each nozzle.

Figure 3 Tipping bucket assembly at the outlet of the runoff plot.

(2.75 m × 24 m) for monitoring the hydrological effects of the treatments. The entire A-frame structure is covered with a polyethylene sheet to avoid wind drift. A microprocessor-controlled simulator regulates oscillation of the nozzles and the rotational speed of the centrifugal pump to deliver the required flow of water for obtaining the required rainfall intensities over a preset time period. The simulator generates rainfall at intensities varying from 75 to 150 mm/h with a coefficient of uniformity between 75 and 81%. A tipping bucket assembly (Figure 3) with a bucket of 3 L capacity at the outlet from the run-off plot collects the run-off without over-spilling. The run-off intensity and amount is automatically recorded by the computer through the reed switch assembly connected to the tipping bucket.

Selection of rainfall intensity

The 30-min rainfall intensity (I_{30}) is usually considered as the most reliable estimate of rainfall erosion potential (Wischmeier, 1959). The maximum 30-min rainfall intensity was calculated using 4 years of available data (1994–1997) from a recording rain gauge located near the rainfall simulator site with a 15-min sampling interval. The maximum I_{30} over the 4-year period was 100 mm/h on 10 September 1997. The maximum values of I_{30} recorded for 1994, 1995 and 1996 were 64, 80 and 79 mm/h, respectively. Hence, rainfall intensities of 100 and 80 mm/h were selected for the experiment. The analysis of rainfall intensity patterns from available records (10 years) under semi-arid tropical conditions suggests that the prevailing erosive intensities in the wet spells are in the range between 60 and 100 mm/h (Meyer & Harmon, 1979). In addition, the effects of the treatments on soil loss could be more pronounced with higher intensity storms.

Experimental site

The experiments during 2003–2004 were conducted on a shallow Alfisol at CRIDA (17°29′N, 78°26′E), Hyderabad, India. The mean annual rainfall is 746 mm and nearly 70% of the precipitation is received during the southwest monsoon season (June to September). In general, the slope of cultivated land varies between 1 and 4%. The texture of the test soil in the run-off plot is a sandy clay loam (sand 58.8%, silt 12.7% and clay 28.5%). The depth of soil is 22 cm and bulk density is 1.54 g/cm^3. The furrows were made using a pickaxe and the size of the furrow was similar to that made by a country plough. The furrows were trapezoidal in shape with a bottom width of 2.5 cm, a depth of 7.5 cm and a top width of 10 cm. The experimental plot had a 3% slope, typical of cultivated land in the region.

Tipping bucket calibration

Under semi-arid tropical conditions, run-off volume and rate from plots less than 100 m^2 can be measured by a tipping bucket assembly (Edwards *et al.*, 1974). A tipping bucket with a 3-L capacity at the outlet from the run-off plot allowed monitoring of run-off rate and volume (Figure 3). The tipping bucket was calibrated using a flow of known rate from a constant head container. A reed switch and a magnet were connected with the tipping bucket system assembly for transmitting in real time the tipping rate of the bucket by an electric signal to the data logger. Calibration equation (1) was used for calculating the flow rate and total run-off volume per minute

$$Q = 0.3617N^{1.103}, \quad r^2 = 0.99 \tag{1}$$

where Q is the rate of flow (L/s), N the number of tips per minute, r the correlation coefficient.

Experiments

Treatments were designed in a way that farmers' cultivation practices across and down the slope could be studied under simulated rainfall. The row spacing for most of the rainfed

Table 1 Row spacing of some selected crops grown in the Hyderabad region, Andhra Pradesh, India

Crop	Row spacing (cm)
Castor	90
Maize	60
Sunflower	60
Cotton	60
Mustard	30–45
Linseed	30
Pigeon pea	60–75
Sorghum	45

Figure 4 Simulator with furrows down the slope at 30 cm spacing.

crops in the region is between 30 and 90 cm (Table 1). Hence, furrows at row spacings of 90, 60 and 30 cm were used for both down and across the slope (Figures 4 and 5).

For each treatment, the simulator was run for 30 min to generate sufficient run-off and to cause the field to be fully saturated. Then the field was left to drain overnight so that the soil was at field capacity the next day for conducting the experiment under similar antecedent moisture conditions.

Figure 5 Furrows across the slope at 30 cm row spacing.

Each experiment was run for 30 min and peak flow rate (L/s), sediment loss per unit of run-off (kg/ha/mm run-off), peak sediment concentration (g/L), run-off (% rainfall) and time to peak (min) were recorded. Furrows were dug across (C1) and down (C2) the slope in the run-off plot and subjected to two rainfall intensities, I1 (80 mm/h) and I2 (100 mm/h). The details of the main experimental treatments for different row spacing were:

R1 furrows at a row spacing of 90 cm
R2 furrows at a row spacing of 60 cm
R3 furrows at a row spacing of 30 cm
R4 control (plot without any furrow).

All the treatment plots were kept weed free. The experimental runs were replicated twice. Run-off water samples were collected manually at 1-min intervals for the estimation of sediment concentration and total sediment load after oven drying.

Results and discussion

The data were analysed statistically (Table 2) in a three factorial completely randomized design (CRD) with row spacing (R1–R4) as the first factor, furrowing practices/furrow orientation (C1 and C2) as the second factor and rainfall intensities (I1 and I2) as the third.

Peak flow rate (L/s)

Peak flow rate is an important factor for the hydraulic design of overflow structures. Furrow spacing and orientation had no significant effect on the peak flow rate (Table 2), although the time to peak was delayed in the case of across slope furrowing. The changes in peak flow with different furrow spacing, orientation and rainfall intensity are depicted in Figure 6a and in the hydrographs (Figures 7 and 8). The marginal increase in peak flow under across slope furrowing may be due to the gradual build-up of water storage and sudden collapse of the furrows that led to run-off water flowing towards the outlet. By contrast, the change in intensity significantly affected the peak flow. The peak flows recorded under the higher intensity of 100 mm/h (I2) were significantly higher than those recorded under the intensity of 80 mm/h (I1). In the case of the control (no furrow treatment), the peak flow rate increased with intensity, from 1.1 L/s with I1 to 1.2 L/s with I2. The combined effects of rainfall intensity and furrow orientation on peak flow rate were not significant. The combined interaction of row spacing, furrow orientation and rainfall intensity also had an insignificant effect on peak flow.

Sediment loss per unit of run-off (kg/ha/mm run-off)

Sediment loss/displacement is an important indicator for evaluating the efficacy of soil conservation measures. Row

Table 2 Effect of furrow orientation, spacing and rainfall intensity on peak flow, sediment loss, peak sediment concentration, run-off and time to peak

Treatment	Peak flow rate (L/s)	Sediment loss (kg/ha/mm of run-off)	Peak sediment concentration (g/L)	Run-off (% rainfall)	Time to peak (min)
Row spacing (R)					
R1 (90cm)	1.21	49.78	4.67	63.26	10.50
R2 (60 cm)	1.26	51.14	5.12	64.11	11.25
R3 (30 cm)	1.26	50.30	4.88	62.20	13.50
R4 (Bare)	1.15	53.70	3.77	64.40	10.50
Furrow orientation (C)					
C1 across slope	1.24	38.02	3.88	59.06	13.63
C2 down slope	1.20	64.44	5.33	67.92	9.25
Rainfall intensity (I)					
I1	1.14	47.74	3.69	62.08	12.00
I2	1.36	54.71	5.52	64.91	10.88
Interaction					
R1C1I1	1.15	32.82	3.52	58.08	12.00
R1C1I2	1.32	39.63	4.29	61.63	11.00
RIC2I1	1.09	58.35	4.77	64.50	10.00
R1C2I2	1.26	68.30	6.10	68.84	9.00
R2C1I1	1.20	30.80	3.24	56.10	15.00
R2C1I2	1.37	35.41	4.02	58.76	13.00
R2C2I1	1.15	65.23	5.38	69.25	9.00
R2C2I2	1.32	73.13	7.83	72.32	8.00
R3C1I1	1.20	26.74	3.20	53.63	19.00
R3C1I2	1.37	31.36	3.74	55.52	18.00
R3C2I1	1.15	66.56	4.45	68.94	9.00
R3C2I2	1.32	76.52	8.12	70.71	8.00
R4C1I1	1.09	50.72	3.25	63.07	11.00
R4C1I2	1.21	56.68	4.29	65.72	10.00
R4C2I1	1.09	50.72	3.25	63.07	11.00
R4C2I2	1.21	56.68	4.29	65.72	10.00
F-test					
R	ns	ns	**	ns	**
C	ns	**	**	**	**
I	*	**	**	**	ns
RC	ns	**	**	**	**
RI	ns	ns	ns	ns	ns
IC	ns	ns	**	ns	ns
RIC	ns	ns	ns	ns	ns
LSD ($P = 0.05$)					
R	–	–	0.62	–	1.78
C	–	2.24	0.44	1.72	1.26
I	0.21	2.24	0.44	1.72	–
RC	–	4.47	0.88	3.44	2.51
RI	–	–	–	–	–
IC	–	–	0.62	–	–
RIC	–	–	–	–	–
CV (%)	22.0	5.8	12.7	3.6	14.7

ns, non-significant; LSD, least significant difference; CV, coefficient of variation. Values are significant at 5% (*$P = 0.05$) and 1% (**$P = 0.01$).

spacing (R) alone had insignificant effects on sediment loss. Furrow orientation (C), intensities of rainfall (I) and the interaction between row spacing and furrow orientation had a significant effect on sediment loss (Table 2). Similarly, the higher intensity rainstorm of 100 mm/h (I2) caused significantly higher sediment loss than the lower intensity of 80 mm/h (I1). Treatment down the slope resulted in higher sediment loss compared with across the slope. The

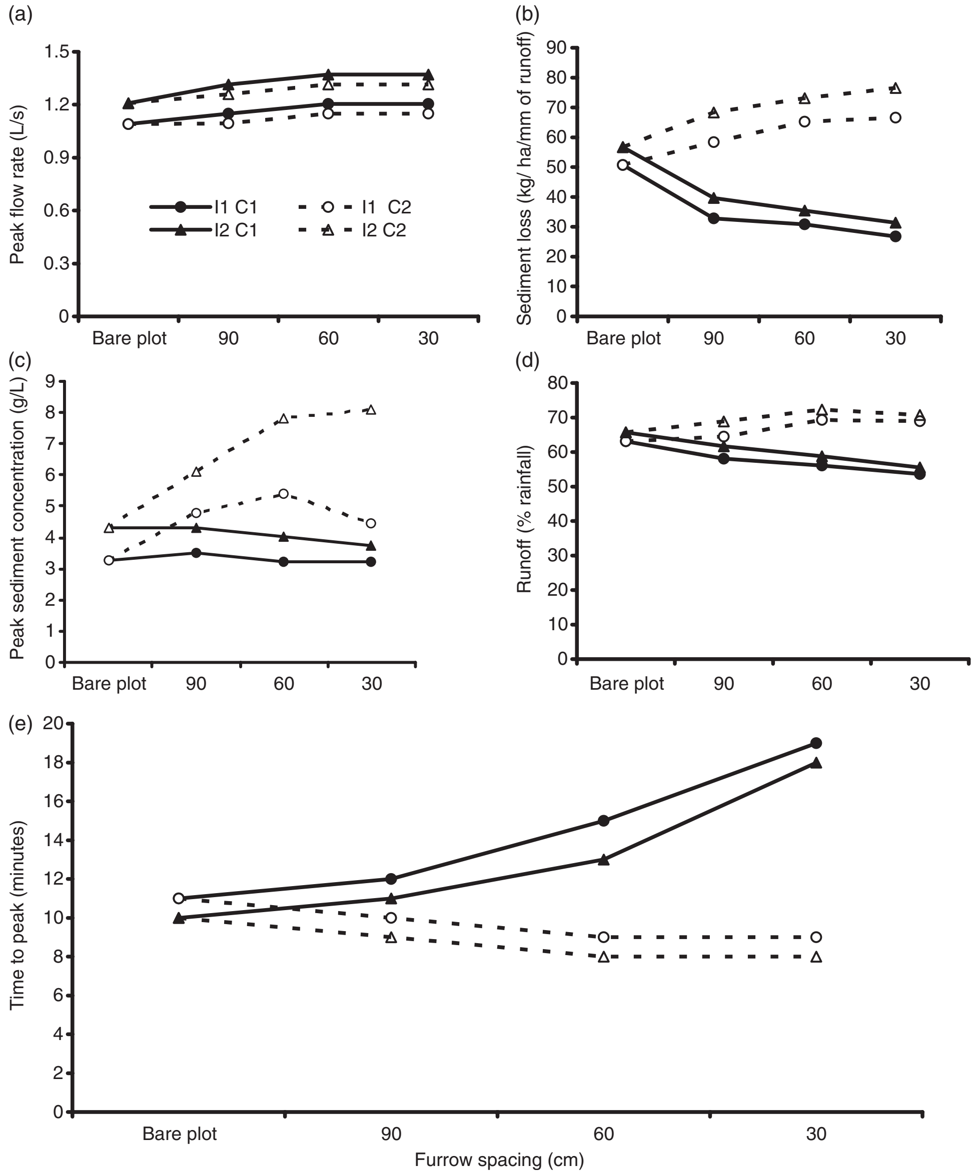

Figure 6 Effects of furrow spacing on (a) peak flow rate, (b) sediment loss, (c) peak sediment concentration, (d) runoff and (e) time to peak across (C1) and down (C2) the slope, under simulated rainfall intensities of I1 and I2.

interaction is significant only between row spacing and furrow orientation. The results showed that the treatments with row spacings of 90 and 60 cm had similar sediment loss rates and had the lowest sediment loss rates across the slope. The same row spacing and rainfall intensities produced higher sediment loss when furrowed down the slope.

The control plot (no furrow) under rainfall intensity I1 yielded a sediment load of 50.7 kg/ha/mm run-off which increased to 56.7 kg/ha/mm run-off under the higher rainfall intensity I2 (Figure 6b). Furrows at 90-cm spacing down the slope recorded a higher erosion rate of 58.4 kg/ha/mm under I1 which increased to 68.3 kg/ha/mm under I2. The corresponding figures for 60- and 30-cm spacing down the slope with I1 were 65.2 and 73.1 and 66.6 and 76.5 kg/ha/mm, respectively, with I2 indicating an increase in sediment loss as a result of reduction in furrow spacing. The increase in sediment loss under furrows oriented down the slope was significant, a 35% increase compared with the control condition under I2. The change in rainfall intensity had a greater and more consistent impact on erosion compared with decreases in furrow spacing.

Furrows across slope with 90-cm row spacing conserved soil by 17.9 and 17.1 kg/ha/mm run-off under I1 and I2, respectively (Figure 6b). The row spacings of 60 and 30 cm resulted in a reduction in sediment yield of 19.9 and 21.3 kg/ha/mm under I1 and 24 and 25.3 kg/ha/mm under

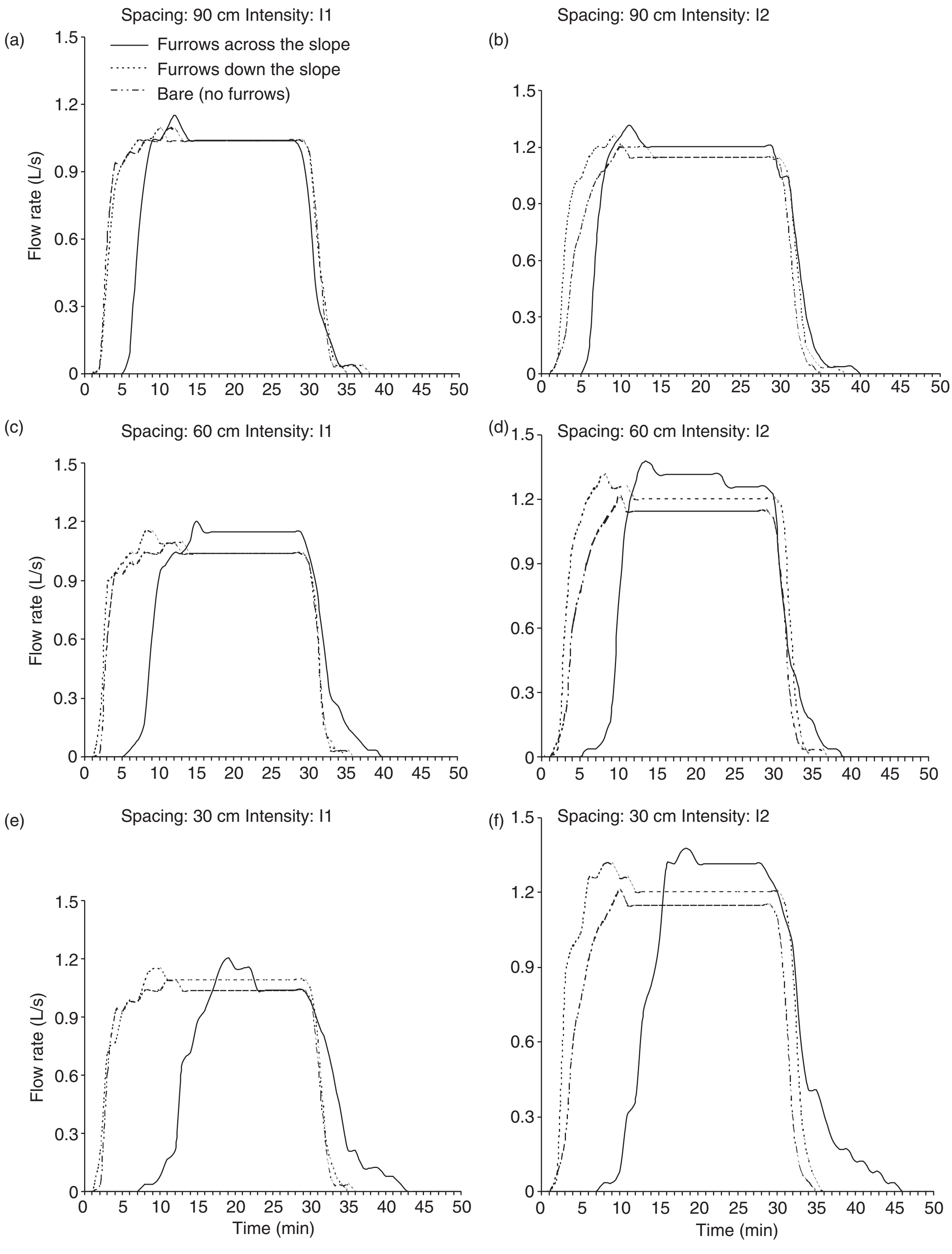

Figure 7 Runoff hydrographs for bare plot and furrows at different spacing (across and down the slope) under rainfall intensities of I1 and I2.

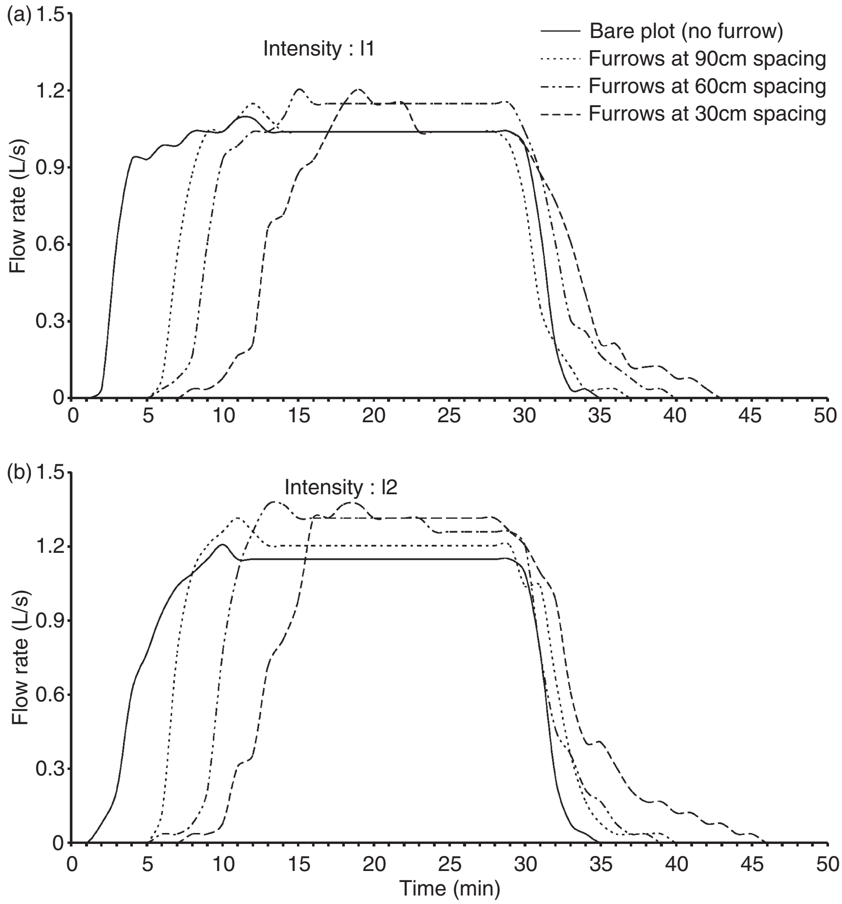

Figure 8 Comparison of runoff hydrographs of different treatments across the slope under rainfall intensities I1 and I2.

I2, respectively. For 60- and 30-cm row spacing across slope, there was no reduction in sediment loss as a result of change in rainfall intensity. In all situations, across slope furrowing resulted in an erosion reduction of approximately 40% compared with no furrow treatment and 69% reduction compared with orientation down slope.

Peak sediment concentration (g/L)

Peak sediment concentration significantly varied with changes in row spacing, furrow orientation and rainfall intensity (Table 2). The interaction effect of row spacing and intensity was not significant. In addition, the interactions of row spacing, rainfall intensity and furrow orientation together were not significant. The control (no furrow, R4) treatment was the best in reducing peak sediment concentration and was similar to across slope furrowing. Down slope treatment with lower row spacing and higher intensity of rainfall recorded higher sediment concentration than that of the control. The treatments with 90-, 60- and 30-cm row spacings were similar in influencing peak sediment concentration. The lower intensity I1 caused lower sediment concentration than from the higher rainfall intensity I2. Across slope furrowing resulted in significantly lower sediment concentration than down slope furrowing. The interaction between rainfall intensity and furrow orientation was highly significant in influencing peak sediment concentration. Lower peak sediment concentration was produced for lower rainfall intensity (I1) with across slope furrowing (C1) compared with the higher values with higher intensity and down slope furrowing (C2). This indicates the effectiveness of across slope furrowing in minimizing peak sediment concentration. All the treatments with across slope furrowing were similar and recorded significantly lower values of peak sediment concentration compared with down slope treatment. The highest peak sediment concentration (8.1 g/L) was observed in 30-cm row spacing down slope under I2 and the least (3.2 g/L) under the same spacing across slope under I1 (Figure 6c).

Run-off (per cent of rainfall)

Run-off is the most important indicator for comparing the effectiveness of water conservation treatments. The effects of furrow orientation and rainfall intensity on run-off were highly significant (Table 2). The interaction of row spacing and furrow orientation together significantly affected run-off production. Across slope furrowing with lower rainfall intensity (I1) recorded significantly lower run-off than down slope furrowing under higher rainfall intensity (I2). The treatments with 60- and 30-cm row spacing across slope were similar in reducing run-off significantly followed by 90-cm row spacing. For a given row spacing, down slope furrowing produced higher run-off than across slope furrowing.

The control plot without furrows yielded 63.1% of the rainfall as run-off under I2 (80 mm/h) which increased slightly to 65.7% with 100 mm/h (Figure 6d). The furrows at 90-cm interval down the slope raised the run-off to 64.5 and 68.8% with I1 and I2, respectively. Furthermore, run-off increased to 69.3 and 72.3% with a furrow spacing of 60 cm down slope with I1 and I2, respectively. The interactions between row spacing and rainfall intensity in reducing run-off were not significant. Opening of furrows down the slope increased both run-off and erosion.

When the furrows were opened at 90-cm row spacing across slope, run-off decreased by 7.9 and 6.2% compared with control (no furrow) under 80 mm/h (I) and 100 mm/h (I2), respectively. When spacing was reduced to 60 cm and further to 30 cm, the run-off was reduced by 11.1 and 15%, respectively, under I1 and by 10.6 and 15.5%, respectively, under I2 compared with the control. Sixty-centimetre spacing which is used for many row crops either increases or conserves run-off depending upon furrow orientation. It increased run-off by 9.8% over the control when orientated down the slope and conserved 11% when aligned across the slope under a rainfall intensity of 80 mm/h. Thirty-centimetre row spacing across the slope conserved run-off by 15% compared with the bare plot condition under I1. Corresponding figures for run-off conservation were 10.6 and 15.5%, respectively, for row spacings of 60 and 30 cm under a rainfall intensity of I2. For both of these row spacing, across slope orientation was beneficial in terms of run-off reduction.

Time to peak (min)

Time to peak is the time required to generate peak flow. With a higher time to peak, there is more opportunity for infiltration and better soil moisture conservation. The treatments and cultivation practices had significant effects on time to peak, but the effects of rainfall intensities were not significant. The interaction effect of row spacing and furrow orientation was significant in influencing the time to peak (Table 2). The row spacing of 90 cm recorded significantly higher time to peak than the rest of the treatments. In across slope furrowing (C1), the time to peak was higher than in down slope furrowing (C2). The times to peak were higher in all the row spacing when laid across slope. A row spacing of 30 cm across slope resulted in the highest time to peak (19 min) when subjected to a rainfall intensity of 80 mm/h (I1) and the time to peak was the lowest (8 min) in down slope treatment under a higher rainfall intensity of 100 mm/h (I2). All row spacings down slope resulted in significantly lower times to peak.

In the control (no furrow), the time to peak was 11 and 10 min when subjected to rainfall intensities I1 and I2, respectively (Figure 6e). Because of furrows across slope at 90-cm row spacing, the time to peak was delayed only by 1 min (time to peak of 12 min) which was not significant. A reduction of only 1–2 min in time to peak was recorded for down slope furrowing compared with the control. When the furrows were laid across slope, the time to peak under I1 was delayed by 4 min in the case of 60-cm spacing and by 8 min for 30-cm spacing. The trend was similar with a rainfall intensity of I2. This is a clear indication of the effectiveness of furrowing across the slopes.

Hydrograph analysis

The run-off hydrographs for the control plot and furrows at different spacing, orientation and rainfall intensities are shown in Figure 7. These show distinct differences in run-off between down and across slope furrowing, and control plot treatments (no furrows). The deviations from the control are more pronounced with higher rainfall intensity, I2. The time for run-off initiation in across slope furrowing ranges between 5 and 7 min (maximum 7 min in the case of 30-cm row spacing). The furrows down the slope and the control yielded run-off within 1–2 min from the start of rain. The effects of row spacing on peak flow are significant as discussed earlier, although there was a small rise in peak flow in across slope furrowing because of the collapse of the furrows and sudden release of run-off. With across slope furrowing, particularly in the case of 30-cm row spacing, the hydrographs (Figure 7e and f) show unsteady flow generated by intermittent storage and release of water through uneven breaches in ridges formed during furrow construction. In the other treatments, the shapes of the hydrographs are fairly uniform. Similarly, in the case of across slope furrowing, the falling limb of the hydrograph extends beyond the rainfall period (30 min) and the run-off was released at lower rates for about 8–16 min depending on furrow spacing. This induced more infiltration which could increase soil moisture and/or enhance recharge to groundwater. Because of faster release of water, down slope treatments resulted in an earlier peak followed by the control (no furrow). After the peak was attained, the flow became steady for the control and down slope treatments. Comparison of the run-off hydrographs from different treatments across the slope under rainfall intensities of I1 and I2 shows the reduction in the area under the hydrographs and the comparative advantage of across the slope furrowing at higher intensities. The hydrographs for row spacings of 60 and 30 cm reflect the beneficial effects of water conservation over the control and down slope furrowing in terms of reduction in run-off as discussed earlier.

Conclusions

Quantification of run-off and soil loss plays a key role in selecting particular conservation measures. In this study, the effects of furrow orientation, rainfall intensity and the interaction of row spacing and furrow orientation were shown to be highly significant in influencing run-off and soil loss. The effectiveness of across slope furrowing was demonstrated. Across slope treatment with a row spacing of 90 cm was as effective as a row spacing of 60 cm. The interaction of row spacing and rainfall intensity had no significant effects on any of the studied parameters. Across slope furrowing was effective in increasing initial abstraction and reducing run-off and associated soil loss (Figure 6). Opening of furrows down the slope is an inefficient method for conserving water and soil. Both 30- and 60-cm row spacing oriented across-slope proved equally efficient and can be recommended as conservation measures. Cultivators need to be educated to plough and sow across slopes following contours.

Acknowledgements

We acknowledge the support from the Director, Central Research Institute for Dryland Agriculture, for conducting this experiment at CRIDA. Assistance from Mr B. Narsimulu, Technical Officer for the experiments and from Mr D. Ramajayam for statistical analysis is acknowledged. Dr Trent Biggs from the Department of Geography, San Diego State University, USA, helped with editing the final draft.

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