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CATCHMENT BASIN WATER HARVESTING AS A MEANS OF IMPROVING THE PRODUCTIVITY OF RAINFED LAND IN UPLAND BALUCHISTAN

by

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Catchment basin water harvesting as a means of improving the productivity of rainfed land in upland Balochistan.

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SUMMARY

Small catchment basins of different size were prepared within bunded fields on gently sloping silty valley bottom soils in upland Balochistan from 1985 to 1988. The ratios of catchment area to cropped area were 1:1 or 2:1. Seasonal rainfalls were 282, 102 and 239 mm in the 1986/87, 1987/88 and 1988/89 seasons, respectively.

Increased water storage in the cropped areas of 55% and 43% of the rain falling on the catchments were observed in the 1:1 and 2:1 treatments. Yields were considerably increased on a cropped area basis by the water harvesting treatments, but not always sufficiently to compensate for the loss of cropped land. The 2:1 treatments suffered from water-logging damage, even in the low rainfall year.

The cost of catchment set-up was low compared to the reduced seed and ploughing costs in the water harvesting treatments, resulting in 21 and 34% reductions in overall costs for the 1:1 and 2:1 treatments. Net benefits were 33% higher than the control for the 1:1 treatment overall, but 27% lower for the 2:1 treatment. Labour inputs were less for the water harvesting treatments, with the result that returns to labour were more than doubled by water harvesting.

Within-field water harvesting with a 1:1 crop:catchment ratio thus reduced risk by reducing investments in seed, animal draft and labour, whilst maintaining yields, suggesting that it could be of considerable benefit to farmers in an environment with a high risk of crop failure. The potential for forming catchments on adjacent unused land, and further research aimed at reducing water-logging damage, could both lead to further improvements in farmer circumstances in upland Balochistan.

INTRODUCTION

Upland Balochistan (27° to 32°N, 66° to 72°E) has a continental semi-arid climate with annual rainfall varying from 150 to 350 mm. Cereal crops, in particular wheat, are grown by most dryland farmers as dual-purpose crops, with the grain being used for human consumption and the straw for animal feed. Two types of land use are practised in dryland agriculture: crops grown on rain-fed land on valley bottoms; and crops grown on 'run-on' land next to hills, in which run-on from ephemeral streams or surrounding rock out-crops is utilized to provide occasional irrigations. Yield expectations are low: 400, 300 and 100 kg ha^{-1} in "good", "normal" and "poor" years respectively on rain-fed land (with a frequency of 0.2, 0.4 and 0.4 respectively); and 800, 600 and 300 kg/ha on run-on land (Rees *et al*., 1988). This paper reports the results of an innovative catchment basin type of water harvesting aimed at improving productivity and yield stability on rain-fed land.

MATERIALS AND METHODS

Catchment basins were established on gently sloping (0.5-1°) valley bottom soils by moldboard ploughing the upper portions of fields to remove weeds and pulverizing the soil with a heavy wooden plank mounted on a three-point hitch behind the tractor. At three of the sites the soils were silty clay loams (sites 1 to 3, Table 1), at the fourth site the soil was a silt loam. Strong soil crusts several centimeters thick formed on the silty clay loam soils after rain, and about one to two centimeters thick on the silt loam. Observations suggested that the crusts increased in depth with repeated wetting, as has also been observed by Sharma, Pareek & Singh (1986). The fields were bounded by earth bunds which are universally raised by the farmers to demarcate ownership and to collect any within-field runoff. Two ratios of catchment:crop area were imposed: 1:1 and 2:1. Control treatments consisted of cropping the whole plot; the plot size was 25x60 m. Four replicates of each treatment were established at each location.

One trial was established in 1986/87, two more in 1987/88, and a fourth in 1988/89. Trial locations are given in Table 1. In 1986/87 and 1987/88 the cropped areas were sown to the local wheat variety, in 1988/89 the cropped areas were divided at right angles to the slope (and direction of water movement and collection) and sown to factorial combinations of local wheat and local barley, with and without nitrogen fertiliser (40 N ha^{-1} in the form of 26% ammonium nitrate, 10 kg sown with the seed in the seed-bed, 30 kg top-dressed at tillering). Following traditional practice 100 kg seed ha^{-1} in 40 cm rows were sown by local farmers using camel draft-power; weeding of the catchment basins was done manually; yield estimates were made by harvesting two rows per plot in successive 5 m lengths at right angles to the slope. In 1986/87 the times taken to manually harvest and thresh (using camel draft-power) entire plots were recorded, and the harvesting and threshing times per kg seed (0.0385 and 0.095 hours kg^{-1}, respectively) wereused to estimate labour requirements in subsequent trials. Catchment set-up times were 5.2 and 7.4 hours ha^{-1} for the 1:1 and 2:1 treatments. Rainfall and temperatures were recorded near each site by local farmers.

In March 1988 at location 1 soil water content was measured gravimetrically to 1 m depth in three replicates at three positions within the cropped areas in each plot: 2 m from the bund, in the center of the cropped area, and 2 m from the catchment or end of plot. Soil water contents were converted to volumetric data using a bulk density of 1.4 g cm^{-3} (ICARDA, 1988).

The following "farm-gate" prices were used for economic analysis of the results (1 US \$ = 20 R in 1989): wheat seed 2 R kg^{-1} (fixed by Government); barley seed 1.75 R kg^{-1}; wheat and barley straw 0.5 R kg^{-1} (in 1987/88 yields were extremely low throughout the province and the price of straw increased to 1.5 R kg^{-1}); N fertiliser 262 R ha^{-1}; tractor rental 60 R hr^{-1}; camel rental 5.5 R hr^{-1}. The cost of the catchment set-up was amortized over five years at ten per cent: 82 and 117 R ha^{-1} for the 1:1 and 2:1 treatments. 10 and 15 hours ha^{-1} per year were allowed for catchment maintenance for the 1:1 and 2:1 treatments; 2 hours ha^{-1} were allowed for fertiliser application.

RESULTS

Weather and crop growth

The seasonal patterns of rainfall at locations 1 and 2 are illustrated in Figure 1, and season totals and averages are summarized in Table 1. In 1986/87 282 mm rainfall was recorded, 123 mm of which fell in July/August, permitting September sowing of the crop. Considerable cold stress occurred during winter, but had little harmful effect on the local wheat variety. In 1987/88 rainfall was extremely low, with no summer rain being recorded. The crops were sown in early February and so had a much reduced growth period. In 1988/89 summer rainfall was not sufficient for autumn sowing and the crops were sown in mid-January. At locations 1 and 2 rainfall occurred after sowing, resulting in soil crust formation above the seedlings, which was broken manually in February, but still resulted in poor crop stands. The more rapidly germinating barley was much more severely affected than the wheat.

Runoff sufficient to inundate the cropped areas of the water harvesting treatments was observed three times in 1986/87 (August, February, March); once in 1987/88 (March); and twice in 1988/89 (January, March). Some redistribution of water also occurred in the control plots, leading to inundation of the area 1-8 m (25 m following the July/August 1986 rains) from the bund. Low infiltration rates on these silty soils led to water remaining on the surface for several days after rain, resulting in visible water-logging damage to the wheat in the 2:1 plots.

Figure 2 shows the soil water profiles recorded in the cropped areas at location 1 in March 1988, following 78 mm rain in five showers. At each position the differences between treatments were statistically significant at $P < 0.005$. The data in Figure 2 suggest that the water harvesting treatments resulted in increased soil water storage below the maximum depth of measurement (1 m) at the positions 2m from the bund and in the center of the cropped areas. Averaged to a depth of 1 m, the data indicate an additional water storage of 43 mm in the 1:1 treatment and 67 mm in the 2:1 treatment, implying runoff efficiencies (water stored in the soil as a fraction of the water falling on the catchment basins) of 55 and 43% for the 1:1 and 2:1 treatments.

Crop yields

Figure 3 shows the typical pattern of crop yields in the cropped areas: in the control plots yields increased with distance from the bund over the first 10 m, declined over the next 10 m and were relatively constant over the next 40 m. Yields in the 1:1 treatment were considerably higher than in the control at each position up to 25 m from the bund, and yields in the 2:1 treatment were higher still.

Yields averaged over the whole cropped area are summarized in Table 2. In 1986/87 yields in the 1:1 treatment were more than double those of the control, but the 2:1 yields were only double those of the control, and less than the 1:1 yields as a result of water-logging damage to the crop. In 1987/88 yields were extremely low, but increased by water harvesting. At location 1, with a two year old catchment basin, yields were considerably increased to the point where seed yield equalled the sowing rate, so that the seed was recovered for the following season's planting, in contrast to the control treatment, where crop failure occurred. In 1988/89 poor stands as a result of soil crusts at emergence undoubtedly reduced yields at sites 1 and 2, and probably reduced the contrasts between the treatments as well. Yields were increased by water harvesting at all locations, but by somewhat less than the 2:1 or 3:1 ratios that would be required to make yields per total land area equal to those of the control.

Table 3 compares the responses of wheat and barley to nitrogen fertiliser in the different water harvesting treatments, averaged over the four trials of 1988/89. The differences in grain yield between sites, water harvesting treatments, crop type and nitrogen regimes were all statistically significant. Nitrogen fertiliser application generally increased yields, and there is an indication that the relative response to nitrogen was greater in the water harvesting treatments than in the control, although this was not statistically significant. At locations 1 and 2 the wheat yielded significantly more than the barley, as a result of the differential effects of the soil crust on the two crops mentioned above. At locations 3 and 4 however, the barley yields were higher than the wheat (significantly so at location 3), as would be expected, given that barley is generally considered both more drought-tolerant and resistant to water-logging than wheat.

Economic analysis

Labour inputs, costs, benefits and returns to labour varied considerably over the three years, mainly due to the large differences in harvesting and threshing times caused by the different rainfall receipts (Table 4). It is particularly noteworthy that the water harvesting treatments reduced costs because there was only one half or one third of the land area to plough, and only one half or one third of the seed was required. The cost of catchment basin set-up was small compared to these savings. Gross benefits for the 1:1 treatment were slightly less (5% overall) than the control treatment, as a result of the small (and not statistically significant) yield reduction on a total area basis, whilst those for the 2:1 treatment were considerably less (30% overall) than those of the control. Accordingly, the 1:1 treatment resulted in higher average net benefits than the control treatment, with only two occasions when net benefits were negative compared to four occasions for the control. The lower yields (on a total area basis) of the 2:1 treatment were only partially compensated for by lower costs, resulting in a reduction in net benefits compared to the control. Labour requirements of the 1:1 treatment were similar to those of the control, but returns to labour were considerably higher as a result of the lower costs and higher net benefits. The lower labour requirements of the 2:1 treatment also resulted in higher returns to labour than the control, despite the lower net benefits.

Table 5 summarizes similar analyses performed on the 1988/89 data of wheat and barley with and without nitrogen fertiliser. Gross benefits were increased by nitrogen in all treatments, and the relative increases were highest in the 1:1 treatment, but in all cases except one (trial 3, 1:1 treatment, barley) the increase in gross benefit due to fertiliser application was less than the increase in cost, leading to a reduction in net benefit and returns to labour. The relative loss due to nitrogen fertiliser was less in the water harvesting treatments, however, as a result of both a lower investment in fertiliser and of higher relative yield responses.

Discussion

In arid and semi-arid regions limited water availability is in almost all cases the major constraint to rain-fed agriculture. It is generally recognized that water harvesting can significantly increase plant production in such areas, and a variety of water harvesting techniques have been practised since historic times in Asia, the Middle East, North Africa and western U.S.A. (Billy, 1981; Singh, 1985; Reij, Mulder & Begemann 1988). The farmers of Balochistan and other parts of Pakistan traditionally practise stream-diversion and the construction of earth bunds as forms of water harvesting, and are able to double crop yields thereby (Oosterbaan, 1983; Rees *et al*., 1988). The practice of concentrating rain-water in a cropped area by treatment of part of a field to increase run-off is therefore likely to be acceptable to Balochistan farmers provided that benefits are adequately demonstrated (Talug *et al*. 1989).

The results presented here demonstrate that the preparation of small catchment basins on rain-fed valley bottom soils by simple ploughing and physical disintegration of soil aggregates, leading to crust formation following the impact of raindrops at the soil surface, represents a low-cost method of generating run-off and increasing crop yields within the cropped area. These yield increases maintained (on the 1:1 crop: catchment treatment) but generally did not increase production on a total (crop + catchment) area basis. Inputs, in the form of seed, animal draft and labour, were considerably reduced however, leading to a reduction in both cost and risk. The 2:1 crop:catchment treatment was less successful, mainly due to water-logging damage caused by too great a concentration of water on these relatively low permeability soils. This is a recognized danger of such direct application water harvesting schemes where the catchment runoff is applied directly to the cropped area instead of being collected in a storage device (UNEP, 1983). Such storage devices generally greatly increase costs, however (UNEP, 1983). Observations suggest that such water-logging damage is a frequent cause of reduced yields in the traditional water harvesting techniques of Balochistan also, yet the farmers are extremely reluctant to allow excess water to escape, even when wheat crops have been flooded for several days. Similar observations have also been made in India (Gupta et al., 1971). It is clear that research aimed at developing appropriate agronomic practices that reduce water-logging damage could considerably benefit the farmers of Balochistan. A variety of low-cost spillways could be installed in the earth bunds around cropped areas to allow the egress of excess water, but this is unlikely to gain immediate farmer acceptance. A more promising solution would be to grow the crops in broad beds, with furrows at one to two meter intervals where the run-off water would collect. A second alternative would be to sow short duration summer crops, such as sorghum, millet or cowpea, after the main rainy period, in April, relying on water harvesting enhanced stored soil moisture for growth. This would also allow germination in a period when soil crusting would be unlikely.

The observed run-off efficiencies of 55% and 43% are not particularly high for these silty clay loam soils, and it is likely that higher efficiencies could be induced by compaction and/or surface treatment with water repellant chemicals (Dutt, 1981; Fink & Ehrler, 1981). However the need for better management of the water on the cropped area, reducing water-logging damage, is clearly of much higher priority at present.

The 1:1 crop:catchment water harvesting practice described here maintained yields on a total land area basis, but generally did not increase them. Large proportions of valley land are currently unutilized however, suggesting that catchments could be set up outside and above current cropped areas. The results presented here suggest that this could be done with a cost of 82 R ha^{-1}, with a resultant increase in gross benefits of 800 R ha^{-1} per year on a long-term basis. It is clear that there is considerable need for further research on both reducing water-logging damage and preparation of catchments on currently unutilized land. However, the practice of catchment basin water harvesting as described here resulted in similar yields with a reduced risk, which could lead to considerable improvements in the circumstances of the resource-poor dryland farmers of upland Balochistan engaged in a high-risk, low return enterprise in an uncertain environment.

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Table 1. Site details and weather summary.

Season	Trial	Location	Elevation (m)	Season rain (mm)	Average temp (C) min	Average temp (C) max	No. of frost days
86/87	1	29°56'N 66°53'E	1750	282	4.4	21.9	96
87/88	1	29°56'N 66°53'E	1750	102	11.2	22.8	4
87/88	2	29°56'N 66°53'E	1750	102	11.2	22.8	4
87/88	3	29°48'N 66°50'E	1650	96	6.6	26.6	13
88/89	1	29°56'N 66°53'E	1750	239	5.9	19.5	30
88/89	2	29°56'N 66°53'E	1750	239	5.9	19.5	30
88/89	3	29°48'N 66°50'E	1650	167	2.4	22.8	61
88/89	4	29°48'N 66°47'E	1950	227	3.9	20.3	48

Table 2. Straw and grain yields (kg ha^{-1} dry weight). (Test crop: local wheat without fertiliser.)

Season	86/87	1987/88			1988/89			
Trial		1	2	3	1	2	3	4
				Grain				
Control	562	25	12	8	196	130	166	159
1:1	1216	96	22	9	223	238	243	259
2:1	1191	90	44	23	317	349	379	241
Mean	990	70	26	13	245	239	263	220
S.E.	225	13.6	4.5	2.2	26.7	23.1	14.7	23.7
		*	**	**	*	**	***	*
				Straw				
Control	1531	105	75	108	392	192	324	388
1:1	2565	281	146	139	584	338	689	676
2:1	2711	352	271	260	782	628	1218	615
Mean	2269	246	164	169	586	386	744	560
S.E.	445	44.0	25.1	16.7	39.3	33.6	83.6	70.7
		*	**	**	**	***	***	*

Standard errors marked with *, ** or *** indicate that differences between the corresponding treatments are statistically significant at $P < 5\%$, 1% or 0.5% respectively.

Table 3. Grain and straw yields (kg ha^{-1} dry weight) of wheat and barley with and without nitrogen fertiliser, 1988/89 trials.

	Grain				Straw			
	C	1:1	2:1	Mean	C	1:1	2:1	Mean
Wheat -N	143	235	284	221	331	558	774	554
Wheat +N	140	263	323	242	280	578	767	542
Barley -N	163	241	321	242	324	572	811	569
Barley +N	177	285	360	274	346	659	894	633
Mean	156	256	322	245	320	592	812	574

	Grain	Straw
S.E.SITE[1]	21.8 **	35.5 ***
S.E.WH	9.0 ***	16.0 ***
S.E.N	6.0 ***	17.7
S.E.CROP	6.0 ***	17.7 *
S.E.SW	14.8 ***	43.3 ***
S.E.SN	12.1	35.4
S.E.SC	12.1 ***	35.4 ***
S.E.WN	10.5	30.6
S.E.WC	10.5	30.6
S.E.CN	8.6	25.0

[1] Standard errors for 1st-order and second-order interactions. Standard errors marked with *, ** or *** indicate that differences between the corresponding treatments are statistically significant at P < 5%, 1% or 0.5% respectively.

Table 4. Labour inputs, gross benefits (G.B.), costs, net benefits (N.B. - excluding cost of labour) and returns to labour (R.L.) for all trials, calculated on a total area basis (wheat without fertiliser as test crop).

	Trial	Labour ($hr\ ha^{-1}$)	G.B. ($R\ ha^{-1}$)	Cost ($R\ ha^{-1}$)	N.B. ($R\ ha^{-1}$)	R.L. ($R\ hr^{-1}$)
Control	86/87 1	190	1890	483	1407	7.4
	87/88 1	28	208	343	-135	-4.8
	87/88 2	26	137	339	-203	-7.7
	87/88 3	26	178	338	-160	-6.2
	87/89 1	51	588	387	201	3.9
	88/89 2	42	356	370	-14	-0.3
	88/89 3	47	494	379	115	2.4
	88/89 4	46	512	378	134	2.9
1:1	86/87 1	190	1857	409	1448	8.7
	87/88 1	29	307	263	44	1.5
	87/88 2	24	132	253	-121	-5.1
	87/88 3	23	113	251	-138	-6.0
	87/89 1	37	369	279	90	2.4
	88/89 2	38	323	281	41	1.1
	88/89 3	39	415	282	134	3.5
	88/89 4	40	428	284	144	3.6
2:1	86/87 1	123	1246	322	924	7.5
	87/88 1	27	236	226	10	0.4
	87/88 2	25	165	222	-57	-2.3
	87/88 3	24	145	220	-75	-3.1
	87/89 1	37	342	246	96	2.6
	88/89 2	39	337	248	89	2.3
	88/89 3	40	456	251	205	5.1
	88/89 4	34	263	239	24	0.7
Weighted means[1]:						
	C	88	851	401	450	1.1
	1:1	85	808	315	598	2.7
	2:1	62	593	264	329	2.8

[1] Long-term means weighted for the number of trials per year.

Table 5. Labour inputs, gross benefits (G.B.), costs, net benefits (N.B. - excluding cost of labour) and returns to labour (R.L.) calculated on a total area basis, averaged over the four 1988/89 trials.

		Labour ($hr\ ha^{-1}$)	G.B. ($R\ ha^{-1}$)	Cost ($R\ ha^{-1}$)	N.B. ($R\ ha^{-1}$)	R.L. ($R\ hr^{-1}$)
Control	Wheat -N	47	488	375	109	2.2
	Wheat +N	50	526	644	-118	-2.5
	Barley -N	44	416	348	68	1.2
	Barley +N	45	385	610	-225	-5.5
1:1	Wheat -N	38	384	281	102	2.6
	Wheat +N	42	450	418	32	0.7
	Barley -N	38	339	268	71	1.6
	Barley +N	41	374	403	-29	-1.6
2:1	Wheat -N	38	349	246	103	2.7
	Wheat +N	40	390	336	53	1.2
	Barley -N	36	295	234	61	1.2
	Barley +N	38	316	324	-8	-0.8

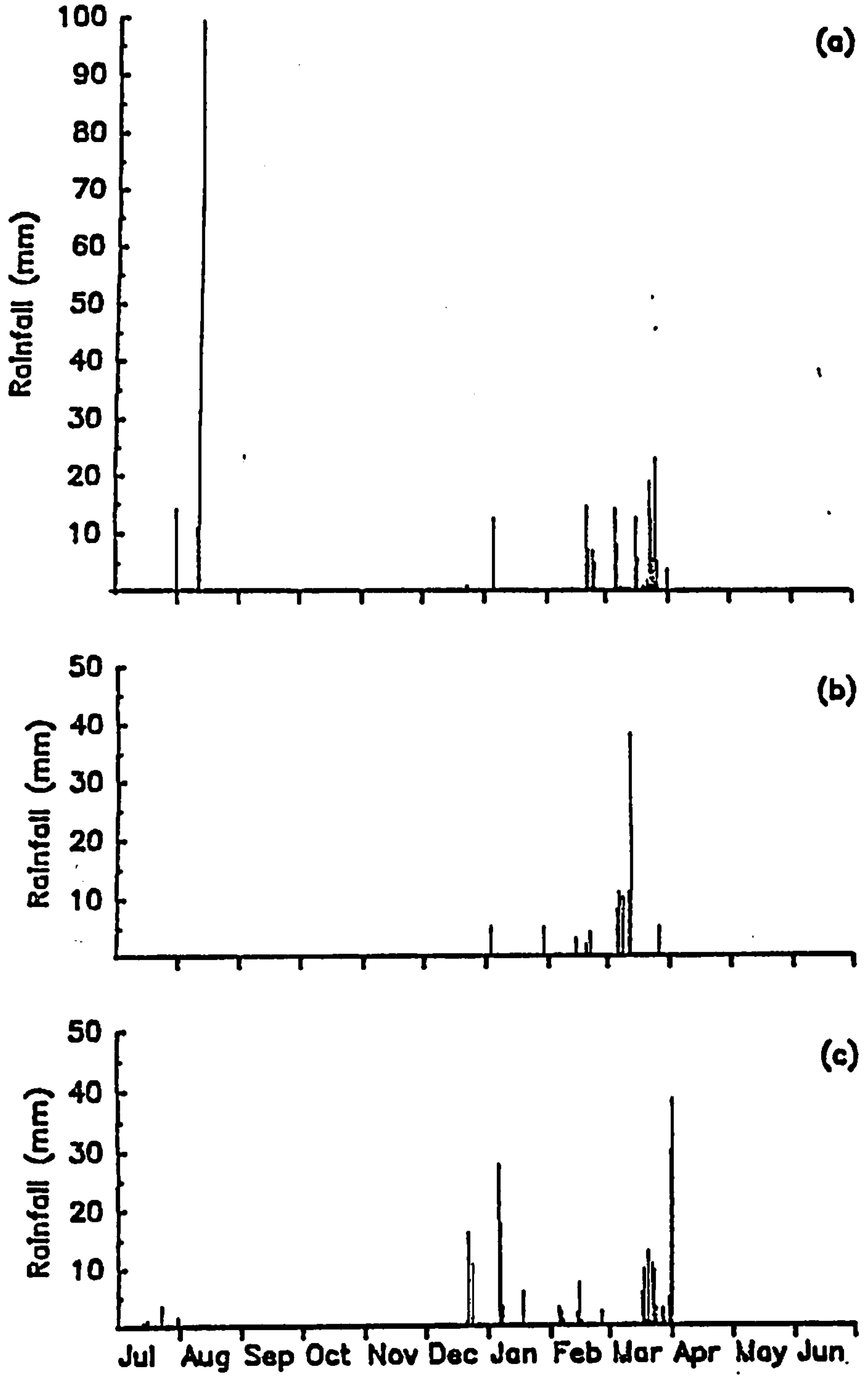

Figure 1. Daily rainfall at locations 1 and 2;
(a) 1986/87; (b) 1987/88; (c) 1988/89

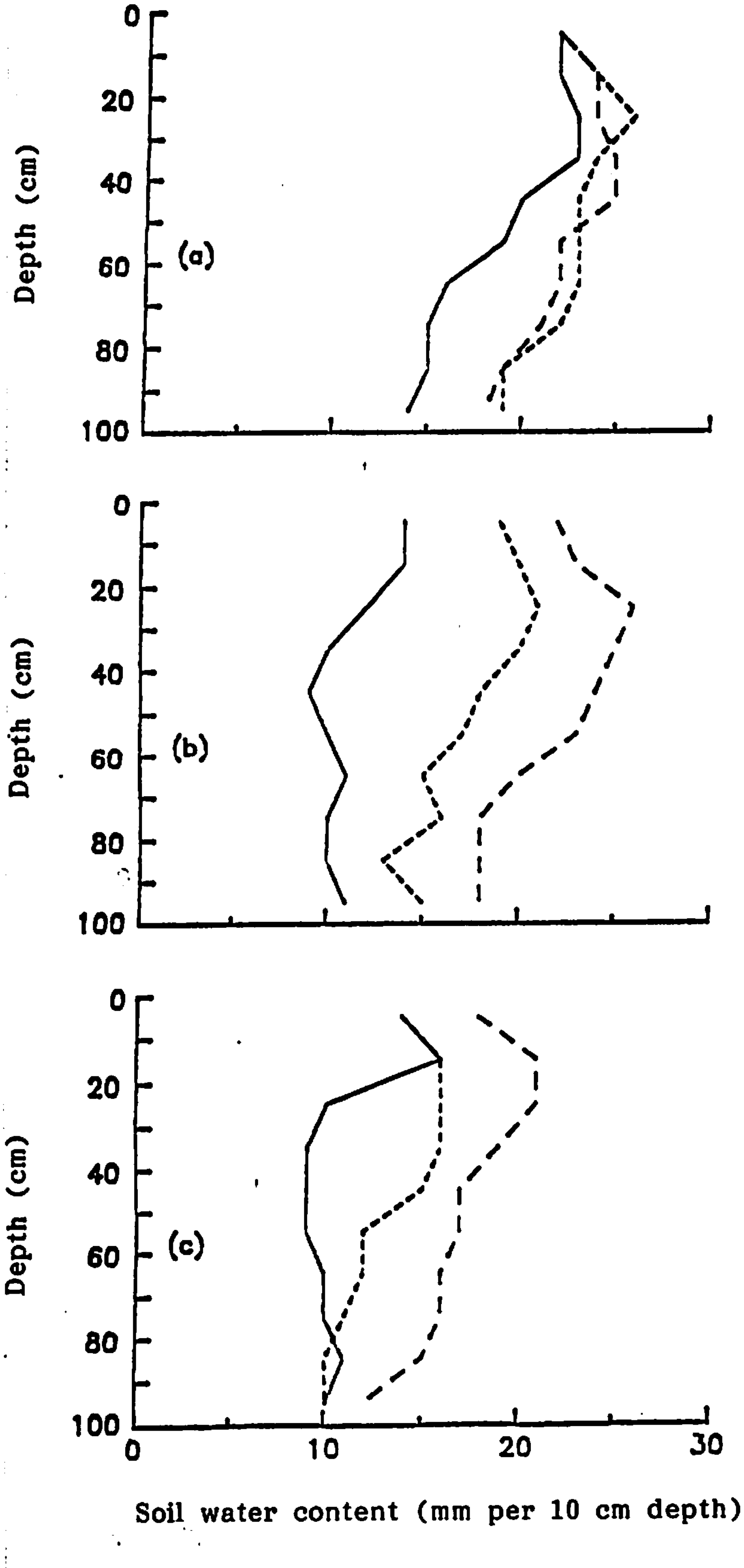

Figure 2. Soil water content of cropped soil at different positions in the 1987/88 trial at location 1.
(a) 2m from the bund; (b) center of cropped area; (c) 2m from the end of the cropped area.
——— Control; ..... 1:1 ------2:1

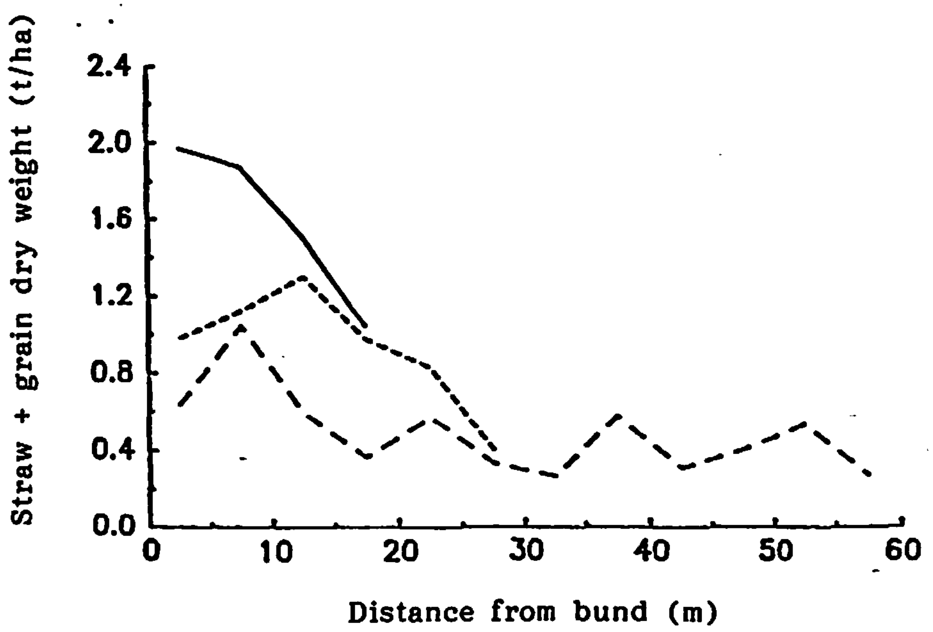

Figure 3. Straw + grain yields at increasing distance from the bund, 1988/89 trial at location 3.
- - - - Control ----- 1:1 —— 2:1