THE MART/AZR PROJECT

HIGH ELEVATION RESEARCH IN PAKISTAN

Pakistan Agricultural Research Council

ARID ZONE RESEARCH INSTITUTE

Brewery Road, Quetta, Pakistan.

No. 6

IMPROVEMENTS IN WATER USE EFFICIENCY IN BARANI ARABLE AGRICULTURE IN BALUCHISTAN

by

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1987

MART/AZR PROJECT RESEARCH REPORTS

This research report series is issued by the Management of Agricultural Research and Technology Project/Arid Zone Research Component (MART/AZR). This project is sponsored financially by the Mission to Pakistan of the United States Agency for International Development (USAID).

The project contract is implemented by the International Center for Agricultural Research in the Dry Areas (ICARDA) and Colorado State University (CSU) at the Pakistan Agricultural Research Council's Arid Zone Research Institute (AZRI).

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IMPROVEMENTS IN WATER USE EFFICIENCY IN BARANI ARABLE AGRICULTURE IN BALUCHISTAN

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Presented at the
INTERNATIONAL SEMINAR ON THE MANAGEMENT OF ARID LANDS
APRIL 26-28, 1987, ISLAMABAD

PAKISTAN NATIONAL COMMITTEE ON
UNESCO'S MAN AND THE BIOSPHERE PROGRAM

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SUMMARY

1. A general climatic description of upland Baluchistan (the continental semi-arid mediterranean zone) is given, and rainfall probabilities for selected sites are analyzed.

2. Traditional farming practices (ridge planting, bunding, diversion of ephemeral streams) are described and evaluated with respect to their effectiveness in harvesting additional water for crop growth.

3. Preliminary results of (a) an improved water harvesting practice; (b) an improved tillage practice (increased infiltration) and (c) use of phosphate fertilizer (improved water use efficiency) are evaluated in terms of increased yields and yield stability.

INTRODUCTION

Situated in the desert belt between 25° N and 32° N Baluchistan has an arid or semi-arid climate, with annual precipitation varying from 50 mm in the West to over 400 mm in the East (Figure 1). Physically it consists of an extensive plateau of rough terrain divided into basins by ranges of sufficient height and ruggedness to pose obstacles to air movement. Rainfall generally occurs in two seasons: winter (November to March/April), as a result of western disturbances in the anticyclonic system extending from Siberia to Iran; and summer (July to September/October) as a result of monsoon storms originating in the Bay of Bengal and the Arabian Sea. Most of Baluchistan is on the fringes of the monsoon area, and so does not receive large or reliable amounts of summer rainfall. The proportion of annual rainfall received as summer rains varies from less than 10% to over 60%, increasing in a North-South and West-East direction.

The variation in elevation, from sea level to over 3000 m results in a wide range of temperature and rainfall regimes (Figure 2). Baluchistan has been divided into two major crop ecological zones by Rafiq (1976), as shown in Figure 3. Based principally on location of the mountain ranges, most of Baluchistan south of 30° N has been classified as hot sub-tropical desert, where the rainfall varies from 50 to 150 mm and the principal land use is rangeland grazing, with some irrigated agriculture particularly in the north easterly areas of Kacchi and Sibi districts. The Northern areas, and a large "extrusion" of high elevation area into the hot subtropical desert zone (Kalat and most of Khuzdar districts) have been classified as continental semi-arid mediterranean, where rainfall varies from 200 to 350 mm and the principal land usage is rangeland grazing, irrigated cropping and barani (or dryland) cropping (Figure 3). The principal barani cropping activity in this higher elevation, lower temperature zone is winter wheat, with some barley and lentil production, and also some sorghum is grown during the kharif season. The Arid Zone Research Institute (AZRI) is currently focusing its efforts in Baluchistan on this continental semi-arid mediterranean zone.

Within this major zone there is also considerable variation in temperature and rainfall, resulting in a wide range of environments for winter wheat production. Table 1 presents some meteorological data for selected stations in Baluchistan where AZRI is conducting research. Minimum temperatures are frequently below freezing from mid-November to the end of January in the three higher elevation areas with maximum temperatures in June and July from 30° to 35°C. Detailed data for Khuzdar are not currently available, but various sources indicate that freezing temperatures during winter are rare, whilst summer temperatures of 38° to 40°C are not uncommon. The higher elevation areas are also more northerly and receive most of their rain during the winter months, whilst Khuzdar receives mainly summer rainfall. The normal cropping pattern for winter wheat in the higher elevation areas is: (1) plow the soil following July/August monsoon rains, and then level the soil to reduce evaporative losses; (2) plant in September; (3) cut the green wheat for fodder in November/December *if* good growth has occurred; (4) crop dormancy from December to February; (5) renewed crop growth from mid-February; (6) harvest the crop in June. In Kalat the lower temperatures can delay harvest until July, whilst in Khuzdar the higher temperatures result in a shorter crop season and a limited dormancy period (if any), with planting in October and harvesting in May.

Table 2 presents rainfall probabilities for Quetta and Kalat. This table shows the maximum rainfall that can be expected at a given level of probability, ie. in January the monthly total rainfall can be expected to be 43mm or less 50% of the time at Quetta, and 31mm or less 50% of the time at Kalat. The low dependability of the critical summer rains is immediately apparent from this table. If the summer rains do not occur, or are insufficient to justify planting in September, farmers have two options: plant into dry soil in October/November and hope for rains early enough in December to germinate the seed; or delay planting until

February and use a spring-type variety of wheat. (Note however that the rainfall probabilities for Khuzdar, where local scientists and farmers expect mainly summer rains, can be expected to show a very different pattern from Table 2.)

It is clear from this data that attempting to grow wheat for grain in this environment is a high-risk, low return exercise. However, the practice of growing wheat as a dual purpose crop, providing both fodder for animals, and if conditions are favorable, grain for human consumption, increases the chances of getting some return from this enterprise. The need for farming practices that make the most efficient use of the scanty rainfall resource in upland Baluchistan is apparent.

The soils of the area are classified (FAO system) as lithosols (very shallow) on the mountain slopes, and strongly calcareous alluvial yermosols in the valley bottoms (homogenized and porous to about 100 cm depth, sandy loams to loamy clays, pH 8.0 to 8.3, 8 to 20 % lime, low organic matter, low N and P content) (Rafiq 1976).

Traditional water harvesting practices

The annual average rainfall of 150 to 350 mm in the barani winter wheat areas of Baluchistan is not sufficient to reliably produce a good crop of wheat. Traditional farming practices have apparently adapted to the environment and attempt to increase the water supply to the crop by a number of means:

1. Ridging

Figure 4a shows the essential features of the "desi-plow", which is used for plowing by some farmers and for planting by almost all barani farmers in the region. The breadth of the instrument is such that when engaged in the soil it pushes the loose soil to either side to form a ridge-furrow system with ridges 8 to 15 cm high. This implement is ideally suited for the proper placement of seed in the seedbed given the rainfall climate of the area: the July/August rains occur at a time when temperatures are too high to plant winter wheat (which would then enter the reproductive phase before winter). When temperatures are more suitable, in September/October, soil moisture has been depleted to a depth of 10 to 15 cm (Fig 4b). The desi-plow enables the farmers to place the seed in moist soil by planting 4 to 6 cm below the bottom of the furrow (Figure 4c). This system is only viable in a rainfall climate such as this, because if rainfall were to occur after planting ponding in the furrows would create anaerobic conditions and seed mortality.

Figures 5a and 5b illustrate the effectiveness of this ridge/furrow system in capturing runoff and increasing soil water supply to the plants. Using an approximate calibration for the neutron probe in this soil, following 47 mm rain the soil water content of the undisturbed soil increased by 24 mm, whereas that of the ridged, cropped soil increased by 57 mm.

2. Ephemeral stream diversion

A common practice in upland Baluchistan is to terrace stony land alongside ephemeral streams, at the top of the valleys near the mountains, and divert some of the streamflow into the fields by dams extending into the streambeds. Streamflow generally only takes place following the more intense storms of the monsoon period (when these occur), but over a period of several years this runoff water, bringing with it soil particles from the surrounding hills can result in very productive fields. However, this form of water harvesting is dependent on the summer monsoon rains, which are unreliable in upland Baluchistan. From Table 2 it can be seen that the probabilities of receiving significant rain (say greater than 20 mm) in July and August are low. If we assume that about 20 mm is the minimum required to generate streamflow, the probability of receiving this in July or August is 0.2 + 0.2 = 0.4 for Quetta, and 0.3 + 0.2 = 0.5 for Kalat, ie. it is likely that streamflow will occur and water/silt harvesting can take place in only one year out of two.

3. Bunding

Large areas of land in the valley bottoms do not receive any water from streams, but do have gentle slopes. Field ownership is usually demarcated by bunds, which have the additional purpose of trapping runoff water. These bunds range from 0.5 to 3 m in height, depending upon the topography of the land. On the heavier soils of the valley bottoms infiltration rates are low, and run-off frequently occurs during the gentler winter rains from surrounding fallow areas and from the top of the fields themselves, to be trapped by the bunds and so is available to the crops in only part of the fields near the bunds.

The bunds traditionally have been built by animal labor (camels, bullocks) but now increasing use is being made of bulldozers and tractors at an approximate cost of Rs.50 to Rs.125 per meter, depending upon bund height (Baluchistan Provincial Government Agricultural Engineering Department, personal communication 1987). The bunds are simply banks of earth; the farmers rely upon time and settling to compact the bunds, and do not incorporate any type of spillway structures. It is estimated that most bunds need some repair work each year (Baluchistan Provincial Government Agricultural Engineering Department, personal communication 1987); the widespread damage done to bunds throughout the province by the heavy rains of August 1986 provides graphic evidence of the need to improve bund construction.

Interventions in Water Harvesting

The quality of terracing and stream diversion is often poor, and considerable improvements are possible. However this would entail major civil engineering works beyond the present capacity of AZRI. Observations of the valley bottom soils have suggested a more modest and practical intervention: crop growth in the upper portions of most fields is usually patchy and poor. We are investigating the possibility of treating this unproductive land to reduce infiltration of rain water and produce increased runoff to be trapped in the cropping area near the bund. Figure 6 illustrates the layout of one of these experiments. Three different treatments are being compared: (1) control, where all the field is cropped; (2) 1:1 treated catchment area: cropped area; (3) 2:1 treated catchment area: cropped area. The treatment of the catchment area is a modification of existing farmer practice: (1) the area is plowed to remove vegetation and loosen the soil; (2) a heavy plank is dragged across the area to pulverize and level the soil; (3) the area is wetted to induce crust formation. This wetting can be artificial, using an outside source of water, or the first rains of the season will cause crust formation after the pulverization treatment of the soil. Other treatments, such as concreting, or mixing salt with the soil to engender a strongly impermeable crust are possible, but these are much more expensive and irreversible than the simple treatment outlined here. This technique has produced a satisfactory crust on both a sandy clay loam soil and a sandy loam soil.

Table 2 shows the first results from this trial. The 2:1 catchment: crop area treatment apparently increased vegetative growth and fodder production by 70%, but this result was not significant in this rather variable farmer's field. Further data will be collected from this and other trials as the crop progresses, but this result is at least suggestive of a potential benefit from this practice.

Figure 7 shows the effects of the different treatments on rain water infiltration, measured near the bunds using the neutron moderation technique. Soil water profiles to 160 cm before and after 47 mm rain between Feb 11 and Mar 3 1987 are presented. The changes in the control treatment are approximately equivalent to 131 mm water, indicating considerable run-off from the surrounding fallow areas into the field. Treating half or two-thirds of the field resulted in an additional 19 and 17 mm respectively, indicating that the surface treatment was successful. In sites where runoff from surrounding areas is uncommon this additional runoff could be crucial to crop survival, particularly in drought years. The main objective of this work is to increase yield stability, by ensuring that some crop is produced even in drought years, rather than to increase yields per se, so the most critical testing of this intervention will be obtained in low rainfall years.

It is appropriate to mention here that the bunds built for this trial, following farmer practice, were broken by the unusually large amounts of runoff in 1986. This emphasizes the need for improvements in bund-making (with proper compaction at the time of construction and stone-pitched spillways at an appropriate height in the bunds).

A mathematical approach to water harvesting is provided by Perrier (1986), who presents techniques for calculating the probabilities of harvesting different volumes of water from different areas of treated soil using information on rainfall, evapotranspiration, infiltration rates and water holding capacities of the soil. This allows the water harvesting practice to be tailored more precisely to the environment. We are currently seeking the necessary data to perform this modeling exercise; the results of our field experiments will enable us to calibrate and refine the model.

Interventions in tillage: increasing infiltration

A recent survey carried out by AZRI has shown that between 25 and 50% of barani farmers in Upland Baluchistan use tractors for at least part of their land cultivation, in agreement with results from the Punjab and NWFP (Byerlee et al. 1986). Tillage is carried out by these farmers using one, or occasionally two passes with a spring-tine cultivator (spring-mounted chisel plow). Results from the Punjab and NWFP have demonstrated that a single pass with a moldboard plow resulted in substantial increases in crop growth and yield compared to the local practice of two to six passes with a spring-tine cultivator (Byerlee et al. 1986). Table 3 presents some results from a tillage trial carried out on a sandy clay loam soil in upland Baluchistan. Over a range of crop types moldboard plowing resulted in an average increase in grain production of 56%, and an increase in straw of 17%. The overall yield levels in this trial were low, but these results strongly suggest that further research into improved primary tillage be continued and extended in upland Baluchistan.

The effects of tillage on crop growth and yield can be complex, and cannot be unambiguously assigned to increased infiltration of rainwater alone; other possible causes could be the breaking up of a hard layer in the soil allowing better root growth, or increased nitrogen mineralization of the inverted soil layer. Soil water observations in the tillage trials should help to clarify these points.

Fertilizer interventions: Use of phosphate fertilizer to improve water use efficiency

Research carried out in Syria on crop water use under different fertilizer regimes has demonstrated that crops fertilized with phosphate can produce more seed and straw yield, without increasing total water use, i.e. with greater water use efficiency (Cooper 1983). Cooper (1983) also provides evidence to support the following mechanisms for this phosphate induced increased water use efficiency in barley: more rapid establishment of green leaf area resulting in a reduction in the proportion of water lost though soil evaporation; increased developmental rates allowing some degree of "drought escape"; reduced root:shoot ratios (greater allocation of resources to harvestable plant parts) and greater overall production of roots facilitating increased water uptake.

Table 5 shows the results of a multilocational fertilizer experiment carried out in 1985/86 in upland Baluchistan. At 3 of the 5 sites yield levels were extremely low (crop failure), but where yields were higher, due to better water harvesting properties of the fields, phosphate fertilizer increased both grain yields (30% increase) and straw yields (10% increase). Analyzed over the five sites, the grain yield response to phosphate was significant at P <2.5%. Other experiments with wheat, barley and lentils have demonstrated significant responses to compound fertilizer, which in the light of Table 5, can be attributed mainly to a phosphate effect. The recent survey carried out by AZRI demonstrated that no barani farmers in upland Baluchistan use any fertilizer on their crops; our results suggest that fertilizer, particularly phosphate, may be advantageous even in this uncertain rainfall environment. However, data from several years will be required to evaluate this properly.

CONCLUSIONS

In response to the harsh environment of Baluchistan, farmers practice a variety of water harvesting techniques, but yields remain low and unreliable. Our research has indicated a number of possibilities for increasing yields and yield stability, but in such a variable rainfall climate these must be tested over several years to provide a proper evaluation. It is possible that even if any one of these interventions (improved water harvesting, improved tillage, use of phosphate fertilizer) is not sufficient to provide an economically viable improvement in yield or yield stability, a combination of all three may do so.

ACKNOWLEDGMENTS

This work is funded by the United States Agency for International Development (USAID) Mission to Pakistan and the Pakistan Agricultural Research Council.

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Table 1. Average monthly total rainfall, average maximum and minimum temperatures, average annual accumulated frost °C for selected stations of the sub-tropical continental highlands of Baluchistan.

	MUSLIMBAGH			QUETTA			KALAT		
	30°45'N 67°52'E 1801 m			30°10'N 67°01'E 1673 m			29°02'N 66°35'E 2017 m		
Month	Temp °C Max.	Temp °C Min.	Rain mm	Temp °C Max.	Temp °C Min.	Rain mm	Temp °C Max.	Temp °C Min.	Rain mm
Jul	35.0	19.9	30	34.6	18.7	21	32.3	16.4	31
Aug	34.4	19.2	19	33.8	16.7	9	31.4	14.8	14
Sep	31.8	14.6	2	30.5	10.0	0	28.4	9.4	2
Oct	25.7	8.2	1	24.6	3.9	3	22.9	3.7	0
Nov	18.7	3.0	7	12.3	-0.4	5	17.4	-0.9	3
Dec	13.9	-0.9	29	11.3	-2.3	25	12.8	-3.6	19
Jan	10.5	-3.1	54	9.7	-2.6	52	9.4	-3.8	55
Feb	13.7	-0.2	46	12.9	-0.3	53	12.1	-1.9	48
Mar	18.2	4.7	43	17.6	3.6	43	16.3	1.9	37
Apr	24.4	9.6	17	23.6	7.4	18	21.7	6.2	15
May	29.7	13.7	16	29.3	11.5	10	27.2	10.3	6
Jun	33.8	17.4	1	33.4	14.9	4	31.3	13.3	3
Mean	24.2	8.8		22.8	6.8		21.9	5.5	
Annual Total Rain			265			243			233
Accum. Frost °C			4.4			9.5			14.3

Temperature data for Khuzdar (27°47'N 66°39'E) 1238m not available at present.

According to Anon. (1984) Khuzdar Annual Total Rain = 148 mm.
Khuzdar Accum. Frost °C = Nil.

Table 2. Rainfall probabilities for Quetta and Kalat.

(a) Quetta 1878 to 1960 data.

Probability	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	Jy-Jn TOTAL
90%	0	0	0	0	0	0	5	5	12	2	0	0	127
80%	0	0	0	0	0	3	17	11	18	4	0	0	158
70%	0	0	0	0	0	5	21	18	23	7	1	0	182
60%	1	0	0	0	0	9	32	29	30	12	3	0	203
50%	3	0	0	0	1	14	43	41	34	17	5	0	222
40%	6	2	0	0	1	23	50	51	41	21	9	0	242
30%	10	6	0	0	3	28	51	56	58	56	26	12	252
20%	21	18	0	2	6	38	69	73	72	39	17	3	279
10%	37	32	3	5	17	71	105	100	91	51	26	12	356
N	82	82	82	82	82	82	83	83	83	83	83	82	82
MEAN	14	10	1	2	7	26	48	47	44	22	10	4	233
CV%	189	169	337	289	222	110	77	85	70	98	124	248	37

(b) Kalat 1882-1970 data.

Probability	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	Jy-Jn TOTAL
90%	0	0	0	0	0	0	1	0	4	0	0	0	100
80%	0	0	0	0	0	0	12	5	7	1	0	0	119
70%	1	0	0	0	0	3	17	8	11	4	0	0	156
60%	3	0	0	0	0	5	23	15	18	6	1	0	163
50%	5	3	0	0	0	11	31	28	23	8	2	0	180
40%	11	6	0	0	0	14	46	34	27	14	4	0	195
30%	23	11	0	0	3	24	51	43	39	18	7	1	209
20%	35	19	0	0	9	32	70	66	49	30	10	3	240
10%	56	33	7	2	20	56	100	97	70	36	16	10	286
N	85	83	85	86	85	83	83	84	84	87	84	86	0
MEAN	20	11	2	1	5	20	43	37	31	14	6	4	200
CV%	184	156	355	534	207	126	89	106	94	102	142	267	42

Table 3. Water harvesting trial, Dasht valley, 1986/87. Barley green fodder production (kg/ha), 23 Dec 1986 (trial planted 4 Sept 1986).

Treatment	Fodder
Control	99
1:1	110
2:1	169
std. error	55.1 no significant differences between treatments

Control - whole field planted to barley.
1:1 - ratio of treated catchment area to cropped area.
2:1 - ratio of treated catchment area to cropped area.

Table 4. Grain and straw dry weights (kg/ha) under different primary tillage regimes, Dasht valley 1985/86. Rainfall during crop growth: 234mm. NO additional runoff receipt.

Grain yields	Sprung-tine Cultivator	Moldboard Plow	Mean
Wheat : local cv.	72	143	108
Zarghoon cv.	58	103	81
PARC81 cv.	117	220	168
Barley local cv.	139	252	196
Lentil local cv.	91	120	106
Mean	95	168	132

Std error between tillage treatments: 9.1 * P<3%
Std error between crop treatments : 11.8 *** P<0.1%

Straw yields	Sprung-tine Cultivator	Moldboard Plow	Mean
Wheat : local cv.	224	385	304
Zarghoon cv.	432	390	411
PARC81 cv.	314	458	386
Barley local cv.	376	412	394
Lentil local cv.	94	102	98
Mean	288	350	319

Std error between tillage treatments: 13.7 * P<9%
Std error between crop treatments : 27.5 *** P<0.1%

Table 5. Response of winter wheat (local variety and "improved" "Zarghoon" variety) to phosphate fertilizer (60 kg/ha phosphate in 46% TSP) and to nitrogen fertilizer (10 kg/ha N in 26% amm. nitrate fertilizer in the seedbed and 30 kg/ha top-dressed at tillering) at 5 sites in upland Baluchistan.

Grain yield kg/ha

Site	P0	P1	N0	N1	Mean	
1	203	272	213	262	238	
2	265	415	380	300	340	Std. error
3	27	25	24	28	26	19.3
4	27	26	27	26	26	P <0.1%
5	50	34	53	30	42	
Mean	114	154	140	129	134	

Std. error 12.2
* P < 2.5%

Std. error 12.2
not significant

Straw yield kg/ha

Site	P0	P1	N0	N1	Mean	
1	504	540	500	544	522	
2	559	639	564	633	599	Std. error
3	255	280	274	261	267	29.0
4	175	221	179	217	198	P < 0.1%
5	232	228	250	210	230	
Mean	345	382	354	373	363	

Std. error 18.4
not significant

Std. error 18.4
not significant

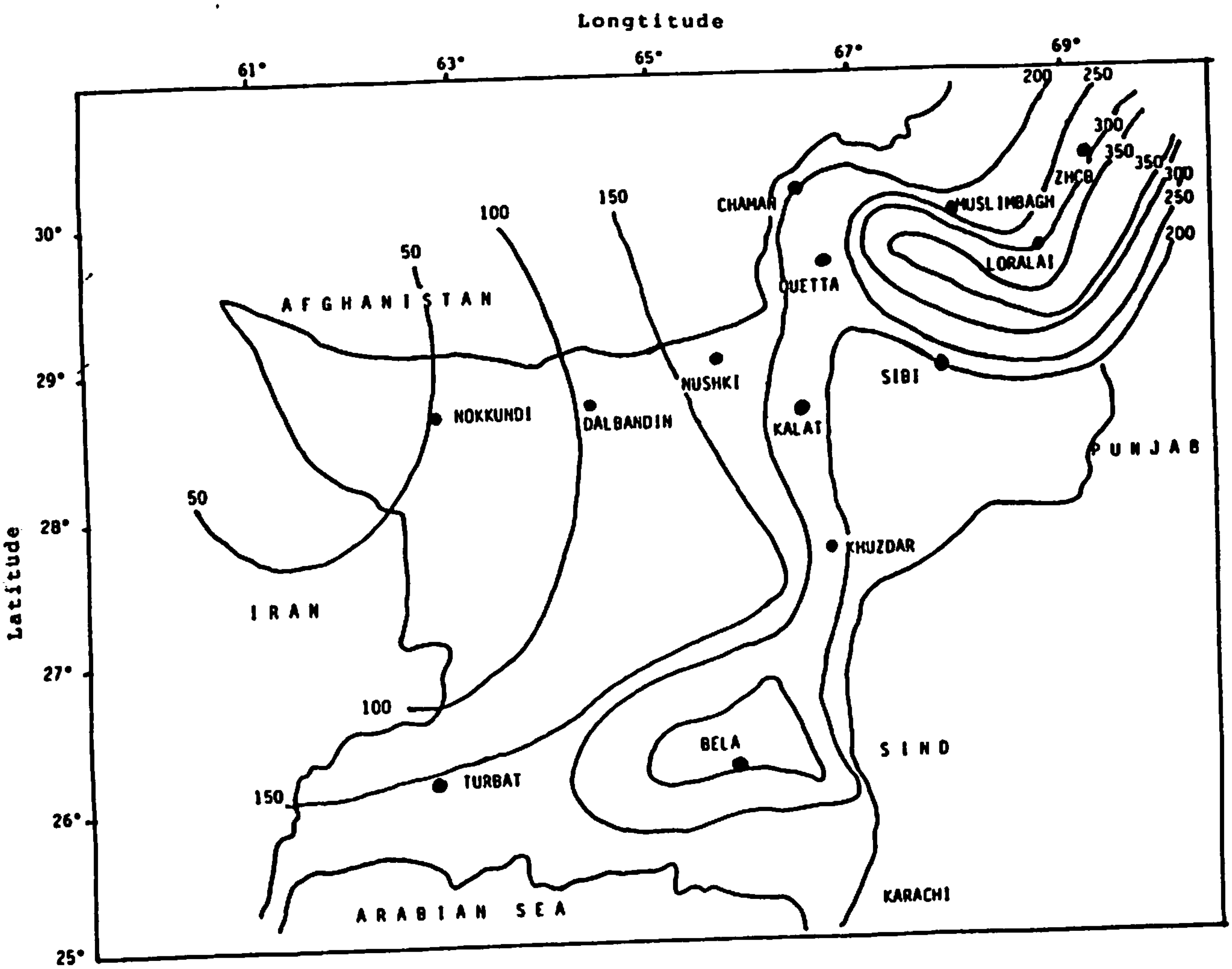


Figure 1. Map of annual rainfall of Baluchistan (redrawn from Anon. 1984).

Figure 2. Mean Monthly Rainfall and Temperature, from Khan (1980).

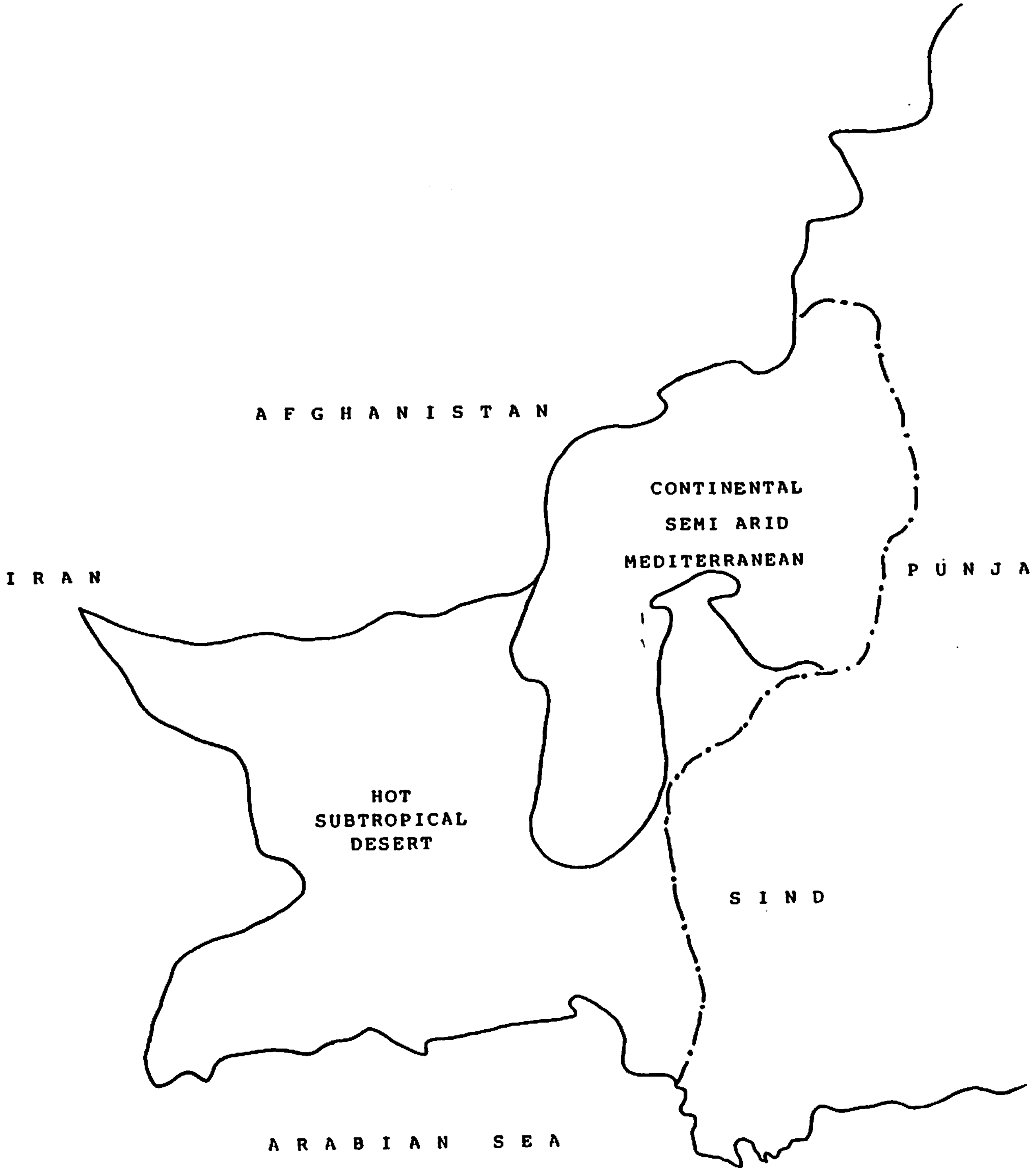


Fig 3 Ecological Zones of Baluchistan (redrawn from Rafiq 1976).

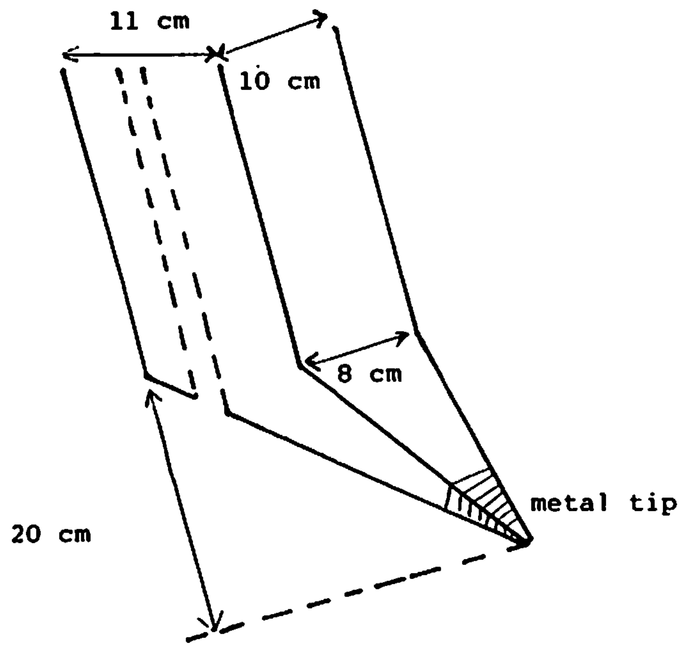
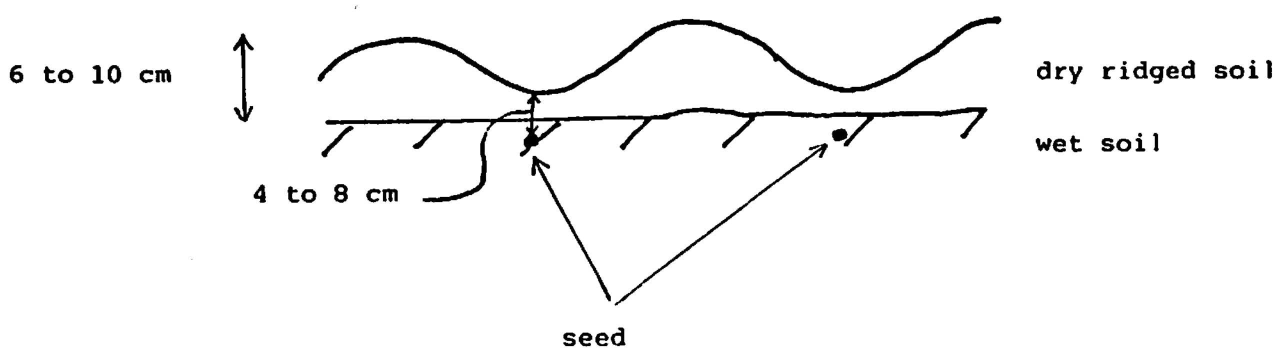


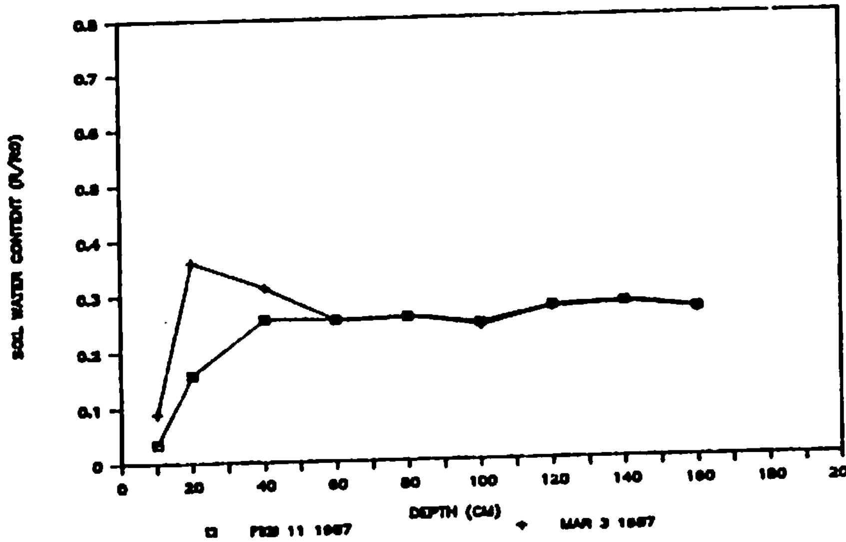
Figure 4a. Traditional desi-plow

Figure 4b. Typical soil water profile at planting

Figure 4c. Typical soil profile after planting



UNDISTURBED SOIL



RIDGED, CROPPED SOIL

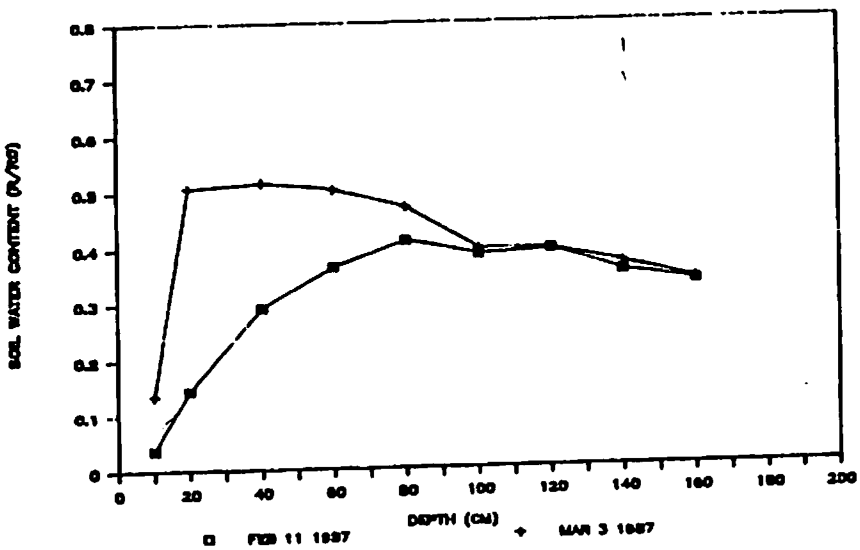
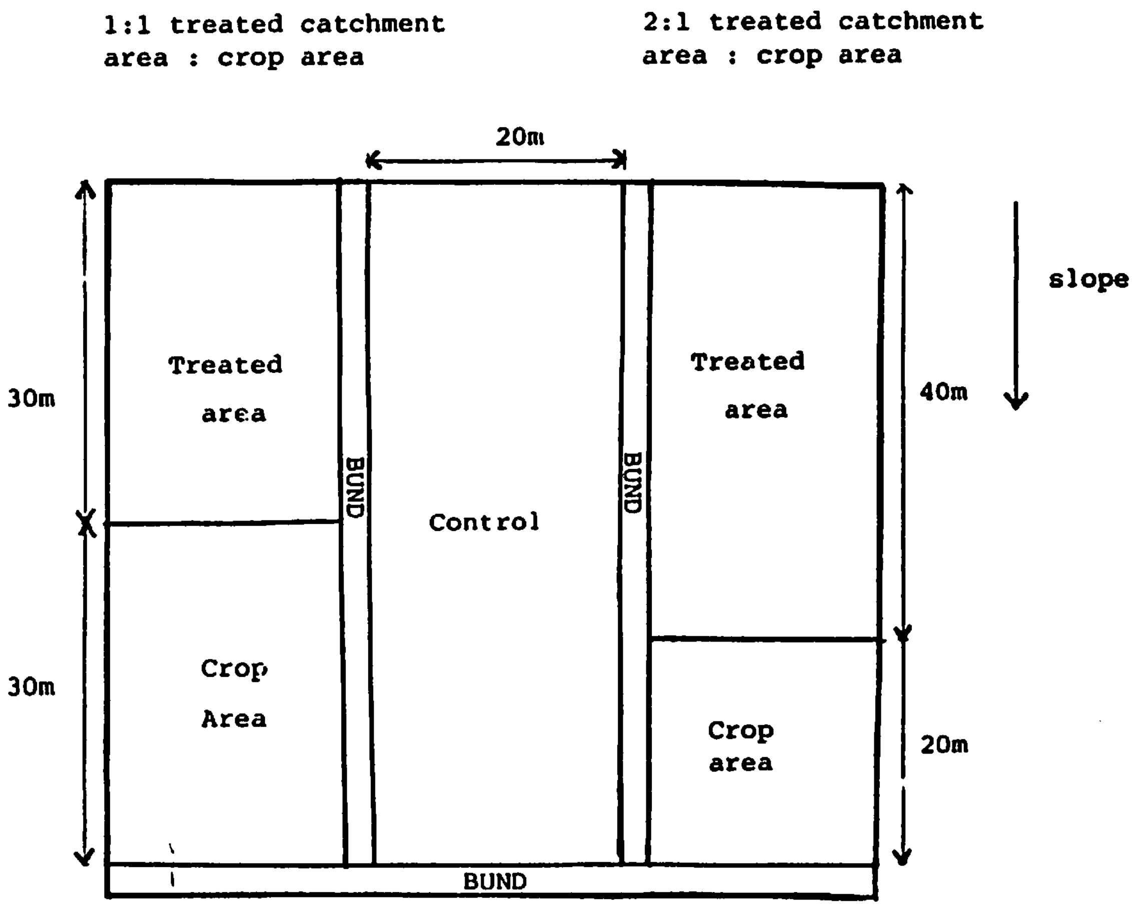


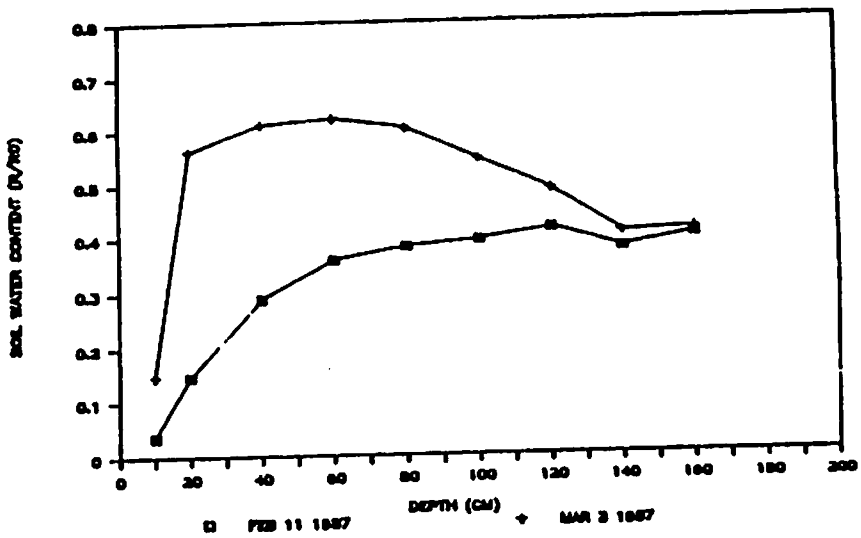
Figure 5. Soil water content, profiles (R/RO - neutron probe rate count as a fraction of shield count) before and after 47 mm rain fall between feb 11 and march 3, 1987.

Figure 6. Layout of one replicate of water harvesting trial in Dasht Valley



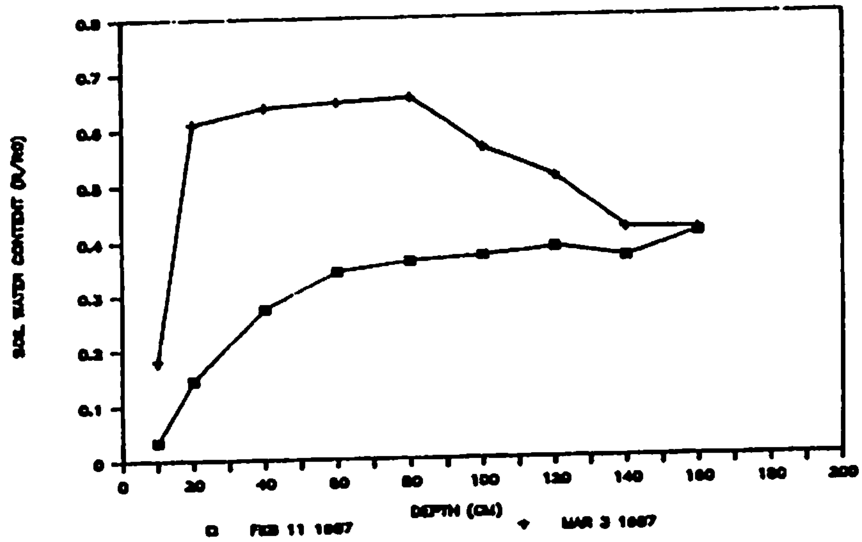
CONTROL

Approx 131 mm
water infiltrated.



1:1 TREATED CATCHMENT AREA : CROP AREA

Approx. 159 mm
water infiltrated.



2:1 TREATED CATCHMENT AREA : CROP AREA

At least 147 mm
water infiltrated
(Soil below 160
cm depth not
monitored.)

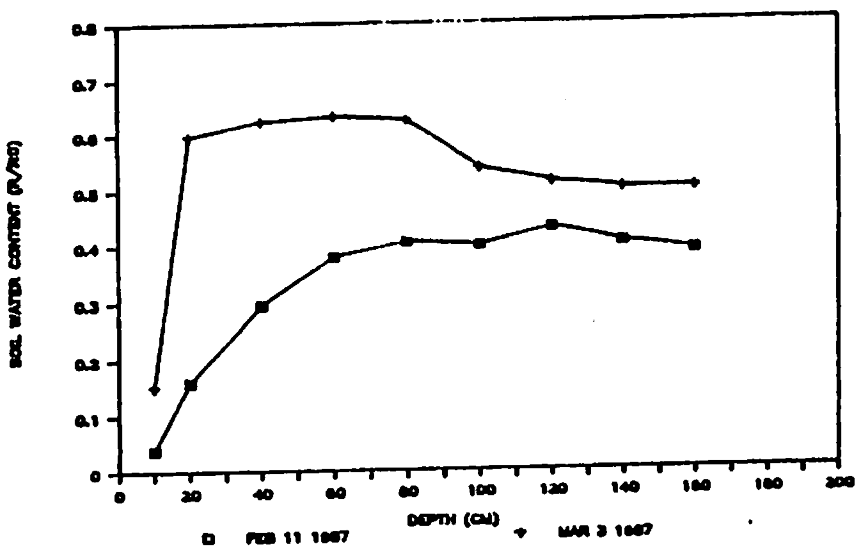


Figure 7.