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SOME ASPECTS OF MOISTURE DEPLETION AND CONSERVATION IN GOZ SANDS AND THEIR IMPLICATIONS FOR IMPROVING AGRONOMIC PRACTICES AND LAND USE IN WESTERN SUDAN

WSARP PUBLICATION No. 45 OCTOBER 1985

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LALIT M. ARYA
(Soil and Water Specialist)

SUMMARY

Goz sands have a natural potential for conserving rainwater. The conservation is achieved by the combined effects of rapid infiltration, rapid drainage, and rapid drying of the surface zone. However, much of the water is available at depths beyond the reach of shallow root systems. Rapid drying of the surface zone produces a natural mulch which acts as an effective barrier against evaporation. The dry layer at the surface, thus, appears to be a desirable feature. However, this is also the zone where seeds are planted. Seed germination and seedling establishment are adversely affected by the surface zone moisture deficiencies. Despite preponderance of sand, crusting occurs in goz sands. The joint effects of rapid drying and increases in mechanical impedance on crusted surfaces are revealed in widespread failure of seedlings. Seedling failure leads to poor yields despite the fact that water is available in the lower depths of the soil profile. The management, therefore, must focus on methods of seedling establishment on one hand and selection of deep rooted crops on the other. This report includes suggestions for improving seedling establishment and profile moisture storage.

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INTRODUCTION

Goz sands are stabilized sands. They cover almost 70 percent of the landscape in North Kordofan and North Dafur. These soils are deep and have high infiltration capacity. However, their water and nutrient holding capacities are very low. Organic matter content appears to be negligible and their is no visible aggregation. Sand content appears to be in excess of 95 percent. There is some silt and little or no clay. These soils are most susceptible to wind erosion. Yet they are most extensively cultivated. The reason appears to be the ease with which they can be worked using hand tools. Cultivation practices on these soils have led to accelerated desertification. Rainfall has been steadily declining over the past 15 years or so and has had the most direct effect on crop yields. Table 1 shows the declining rainfall patterns. Yields for the major field crops for the past several years are presented in Table 2. Data indicate a parallel between the decline in rainfall and the decline in crop yields. The effect of low and unreliable rainfall on crop production is much more pronounced in goz soils than elsewhere.

In view of the general deterioration of the environment and steep decline in crop yields, questions arise as to the most judicious use of the land. Expert opinions suggest that the best use of goz lands would be to preserve them

Table 1. Declining pattern of annual rainfall in the region around El Obeid.

Year	Average rainfall, mm
1941 - 1970	386
1970 - 1977	350
1978 - 1984	280
1984 (9 locations)	132

Table 2. A comparison between yields (kg/ha) of major filed crops in North Kordofan (Sudan) and World estimates for the same crops for dryland areas.

Crop	Estimated[1] dryland yields	Maximum[2] achieved in North Kordofan (1960's)	Mean yields in North Kordofan, Sudan				
			1960's[2]	1974-78[3]	1979-83[3]	1983[3]	1984[3]
Sorghum	800	770	535	289	274	109	36
Millet	600	675	470	314	274	135	31
Sesame	500	440	305	180	173	97	24
Groundnuts	1300	1580	880	605	558	206	73

1. Reference 10
2. Reference 11
3. Statistics Office of the Regional Ministry of Agriculture, El Obeid, Sudan.

under forest and natural vegetation. However, if cropping on goz soils is to continue, sound management practices will have to be evolved and adopted. The Western Sudan Agricultural Research Project (WSARP) is carrying out soil and water conservation trials with the objective of developing improved crop and soil management practices. As part of these trials, certain physical characteristics of the soil and hydrologic processes were studied during the 1984-85 season. Information obtained helps to understand the specific limitations to crop production. This paper reports the results and discusses their implications for improving agronomic practices and land use.

MEASUREMENTS AND RESULTS

Soil Sampling and Bulk Density Measurements: Two soil profiles were sampled in varying depth increments down to a depth of 165 cm. Bulk samples were obtained from each layer for textural and chemical analyses. These samples were sent to Agricultural Research Corporation (ARC) for determination of particle-size distribution, organic matter, pH, and available nutrients. Unfortunately, no results ever came back from ARC.

Bulk densities for each layer were measured using brass cores. Data for a soil profile at the WSARP Farm, El Obeid are shown in Figure 1. For another profile, data are presented in Table 3. Except near the surface, their does not appear to be any compaction. The profile between the depths of 40 to 160 cm appears to be fairly uniform with an average bulk density of about 1.47 g/cm^3.

Surface Crusting and Spatial Variability: Despite preponderance of sand, surface crusting occurs in goz sands. Two types of surfaces were noticed on the goz land during

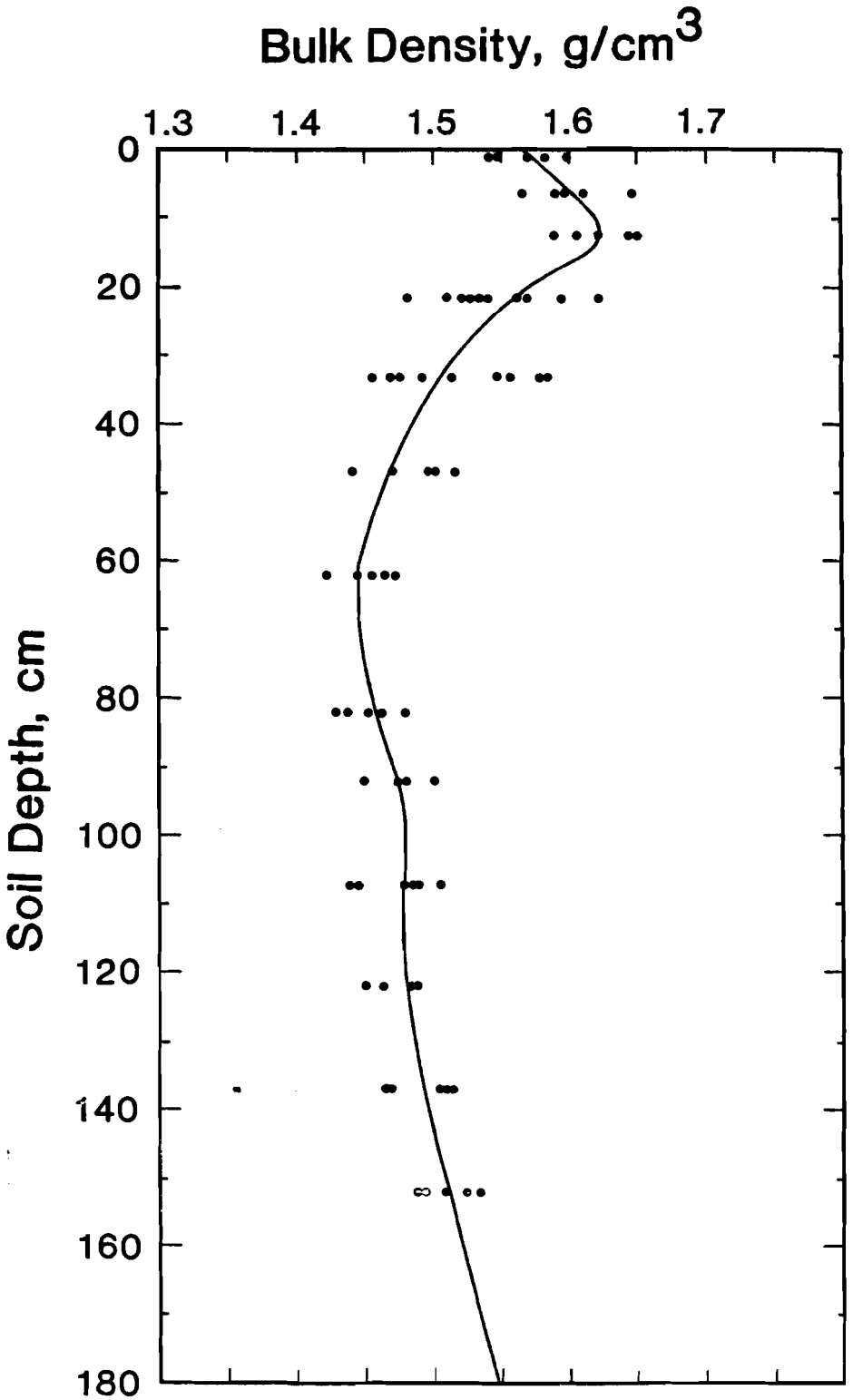

Figure 1. Bulk density profile for goz sand (profile 1), WSAP Farm, El Obeid.

Table 3. Variation in bulk density with depth in goz sand, profile 2, WSARP Farm, El Obeid. Each value is a mean of five samples.

Depth cm	Bulk density g/cm^3
0 - 5	1.544
5 - 10	1.589
10 - 15	1.573
15 - 20	1.590
20 - 30	1.584
30 - 45	1.532
45 - 60	1.520
60 - 75	1.552
75 - 90	1.556
90 - 105	1.550
105 - 120	1.564
120 - 135	1.620
135 - 150	1.634
150 - 165	1.647

the 1984 cropping season. One was with loose sand of variable thickness and the other was a smooth surface exhibiting a crusted appearance. The two types of surfaces occur in a random manner, in patches of varying sizes. At first, this variability was not considered serious, as the soil texture under the two types of surfaces appeared to be the same. Later on, however, it was noticed that seedling emergence in smooth patches was very poor with 100 percent failure in some plots. At this point, penetration resistance as a function of depth was measured using a proctor penetrometer. Data, presented in Figure 2, showed very high impedance under the crusted surfaces. Penetration resistance was quite low under the loose sand. Most of the strength under the smooth surface appeared to be confined to between the surface and 2.5 to 3.5 cm depth. Subsequently, we measured penetration resistance for a fixed depth of 5 cm as a function of water content. Data, plotted in Figure 3, show that penetration resistance under the crusted surface increased rapidly as the drying progressed. It remained quite low under the loose sand. As will be seen later, drying of the surface zone in goz sand is very rapid. It appears, therefore, that the combined effects of rapid drying and increasing mechanical impedance are responsible for poor emergence of seedlings. The pattern of occurrence of these crusted surfaces also creates high spatial variability and affects field experiments. The land needs to be plowed in order to homogenize the soil but special measures will have to be taken to minimize the risk of wind erosion.

In addition to measurements of penetration resistance, 0 to 30 cm samples were taken from 24 spatially distributed locations to obtain data on variations in fertility and other important characteristics of the soil. Surface bulk densities for the 0 to 3 and 3 to 6 cm depths (Table 4) did

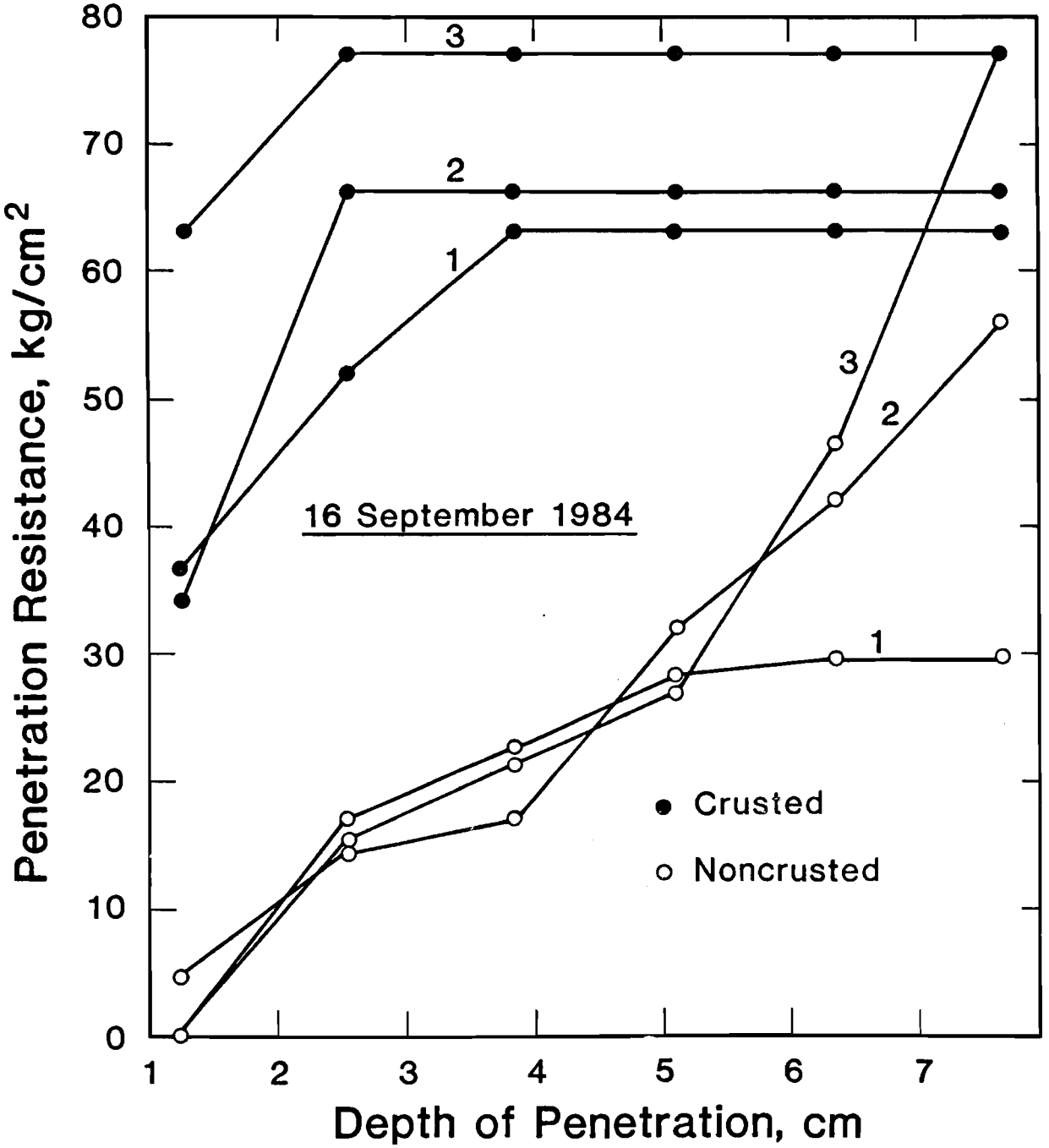

Figure 2. Penetration resistance in goz sand, as a function of depth. Numbers by the curves indicate locations on the farm.

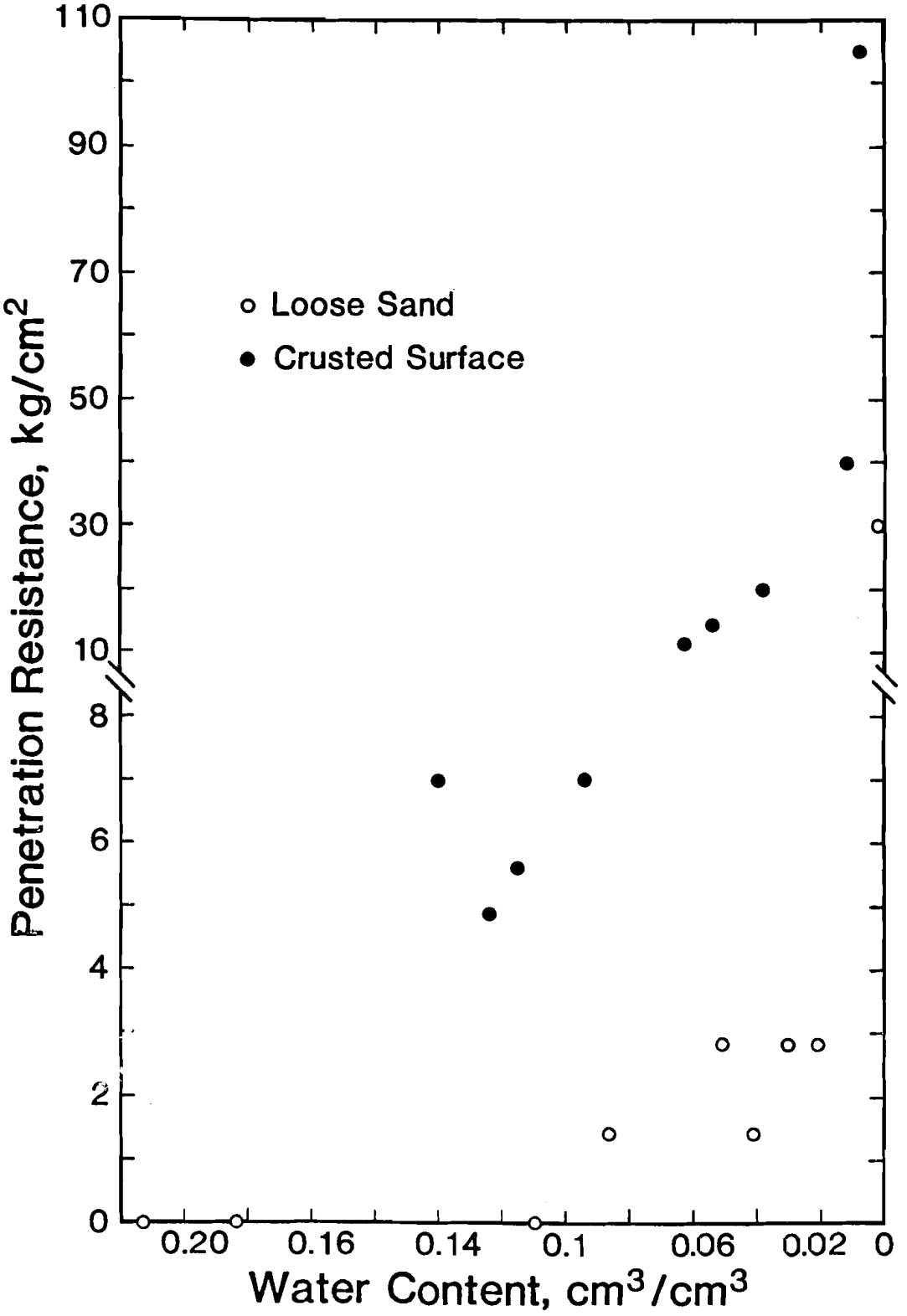

Figure 3. Penetration resistance for the 0-5 cm depth in goz sand as a function of drying.

Table 4. Variation in surface bulk densities under crusted and noncrusted surfaces in goz sand.

	Bulk density, g/cm^3			
	Crusted		Noncrusted	
Locations	0 - 3 cm	3 - 6 cm	0 - 3 cm	3 - 6 cm
1	1.595	1.689	1.586	1.569
2	1.620	1.591	1.588	1.444
3	1.576	1.481	1.642	1.557
4	1.596	1.610	1.543	1.466
5	1.629	1.617	1.590	1.567
6	1.544	1.662	1.645	1.572
7	1.585	1.654	1.596	1.614
8	1.580	1.650	1.599	1.646
9	1.583	1.599	1.618	1.647
10	1.593	1.715	1.676	1.618
11	1.596	1.581	1.627	1.641
12	1.620	1.596	1.645	1.622
Mean	1.593	1.620	1.613	1.580

not appear to be significantly different between the crusted and noncrusted surfaces. Data for other soil properties were not received from ARC.

Soil Moisture Characteristic: Soil moisture characteristic is the relationship between soil water content and the tension (or negative pressure) with which it is held in soil pores and on particle surfaces. This relationship for goz sand was measured using tensiometers and gravimetric sampling of soil moisture. Data, plotted in Figure 4, show that most of the water is held at very low tensions. This implies that most of the water is easily extractable. The traditional limit for wilting is considered to be a tension equivalent to -15000 cm of water. In goz sand, most of the water is released above a tension of -1000 cm of water. Data also indicate that most of the soil pores are large. The effect of large pores is to cause a rapid percolation of water. As will be seen later, goz sands do, in fact, allow a very rapid infiltration and percolation.

Deep Percolation: Downward movement is rapid in goz sand. Water content of a 180 cm deep profile was measured following a heavy flooding (approximately 400 mm application). Total water content of the profile, 4.5 hours after flooding, was 353 mm. It dropped down to 304 mm 21 hours after flooding (see Figure 5). A loss of 96 mm in 21 hours cannot be accounted for by evaporation alone. Pan evaporation for the first 21 hours was estimated to be 9 mm. Soil evaporation would be much less than this value. Therefore, much of the observed water loss must be attributed to drainage past the 180 cm depth. A further insight into the percolation characteristic of the soil is obtained from comparisons of theoretical porosity and measured water contents 4.5 hours after flooding. If we

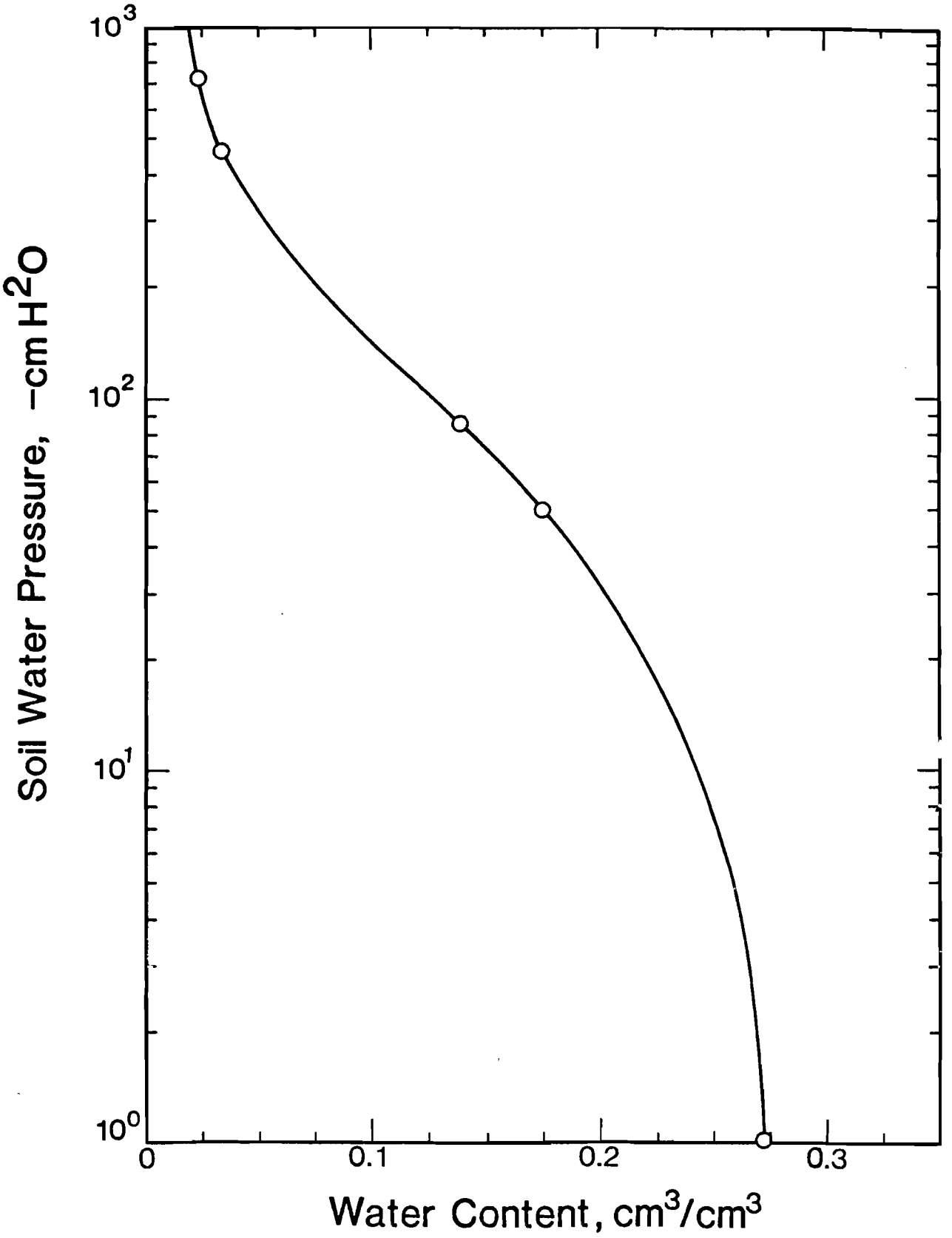

Figure 4. Moisture characteristic for goz sand.

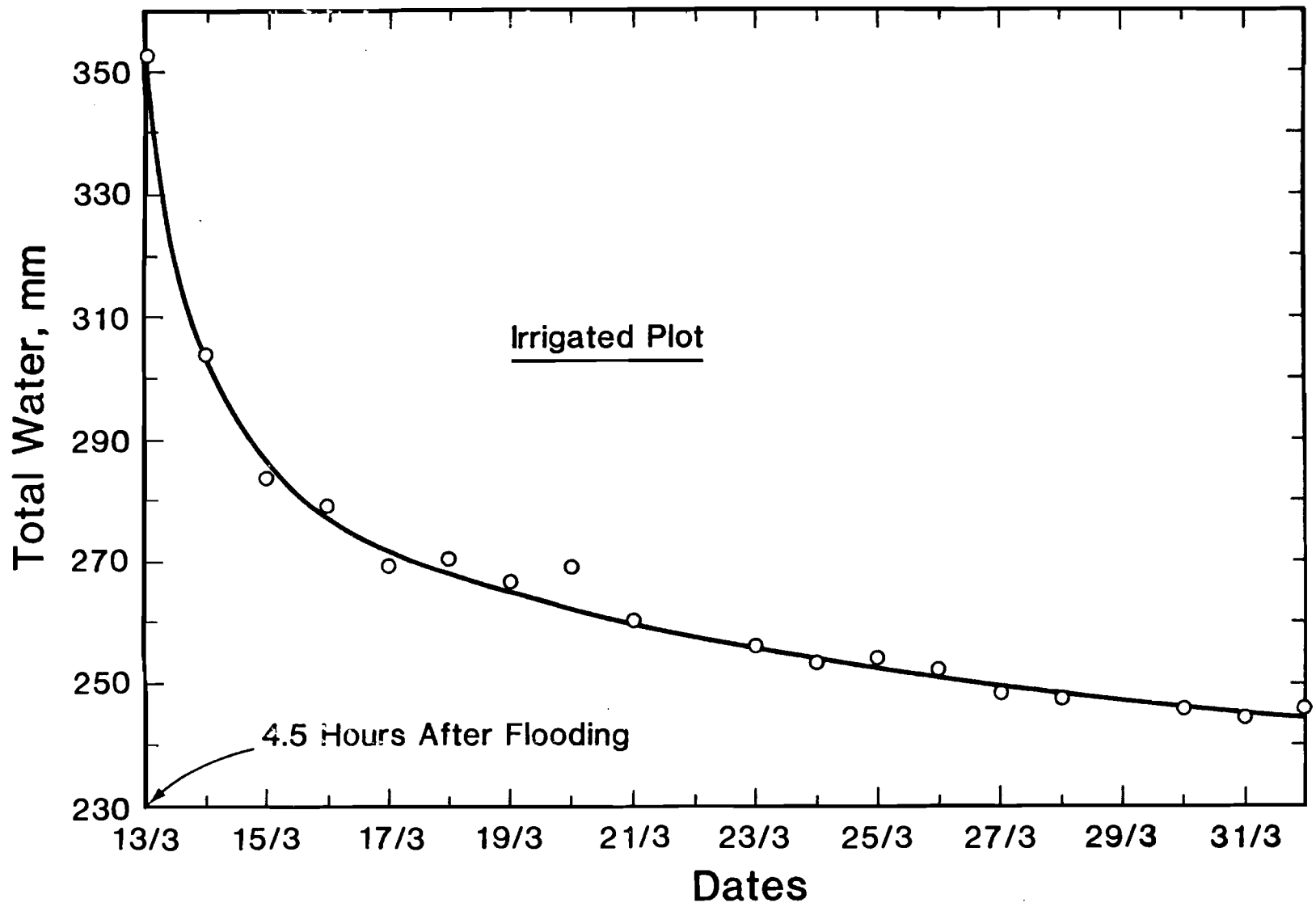

Figure 5. Post-flooding changes in the total water content of a 180 cm deep profile in goz sand.

assume an average bulk density of 1.5 g/cm^3 (see Figure 1) and a particle density of 2.65 g/cm^3, a porosity value of 43 percent is obtained. Theoretically, when all pores are filled, the volumetric water content should be 43 percent. Our measured values of water content, 4.5 hours after flooding, did not exceed 22 percent (see Figure 6). Given that surface evaporation could account for only a small fraction of the total water loss, it is concluded that a rather large portion of the applied water moved past the 180 cm depth in a very short time.

Surface Zone Drying Patterns: Since surface zone moisture conditions are crucial to seed germination and seedling establishment, it was considered important to make an assessment of surface zone drying patterns in goz sands. Two plots were prepared, one in a crusted area and the other in an area with loose sand on the surface. Both the plots were wetted with 30 mm of water. Soil was sampled for moisture content as soon as the free water disappeared from the surface. Samples were obtained in 5 cm depth increments down to a depth of 20 cm. Sampling continued at short time intervals up to 70 hours after irrigation. Gravimetric moisture contents were determined by oven drying and converted to volume basis by multiplying the values with bulk densities for the respective depth increments. Volumetric water contents were converted to equivalent depth of free water for the various 5 cm zones. Depth of free water for the various soil depth increments are plotted as a function of time in Figures 7 and 8. Data show that surface zone moisture loss is, indeed, very rapid. The 0 to 5 cm zone under the noncrusted surface lost almost 76 percent of the initial water content within the first 24 hours. As expected, the rate of water loss decreased with depth but remained quite high for the top 10 cm of the soil. The water loss patterns under the crusted surface were similar; however, the values were somewhat smaller.

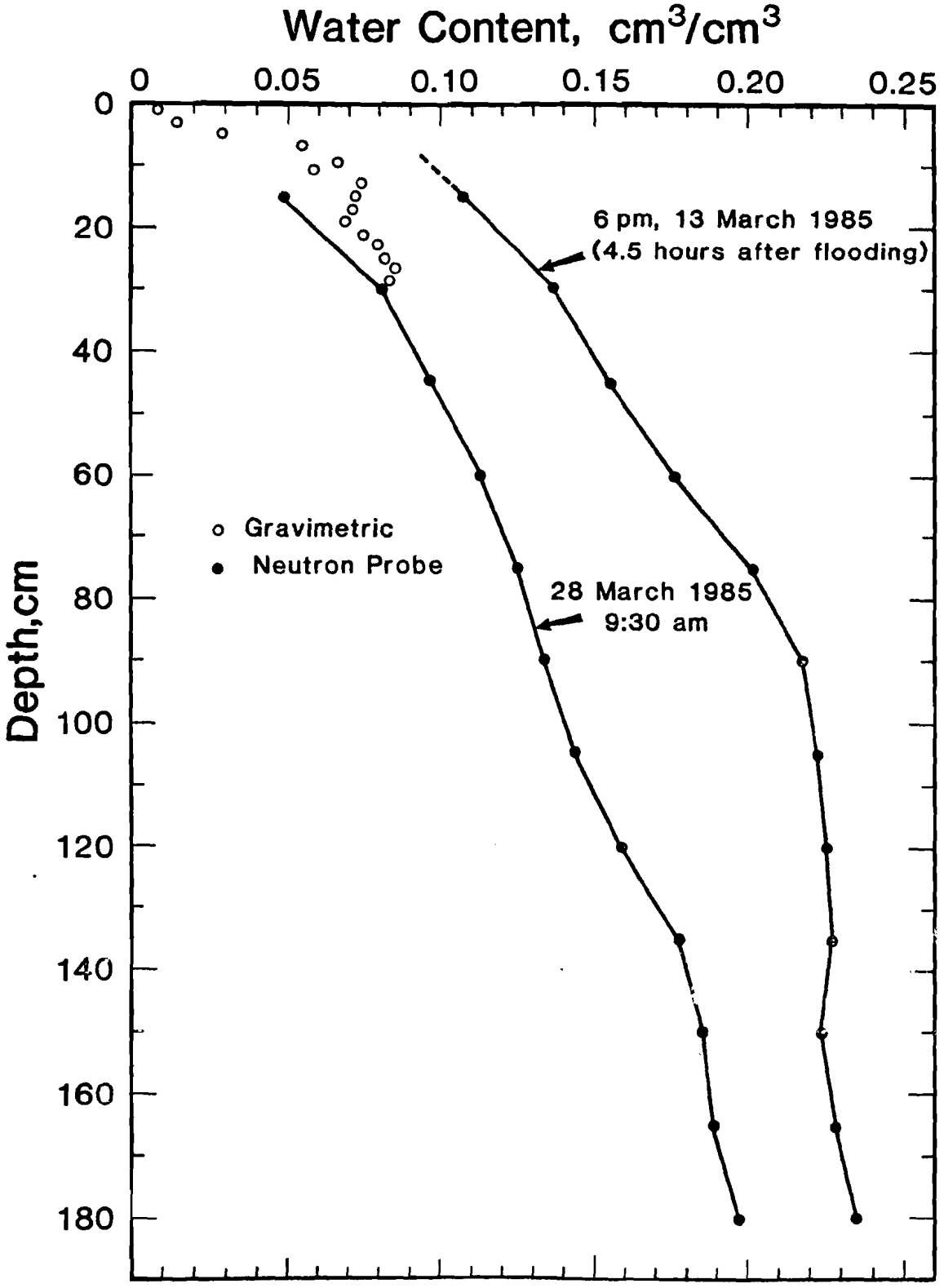

Figure 6. Moisture profiles in goz sand following a heavy irrigation.

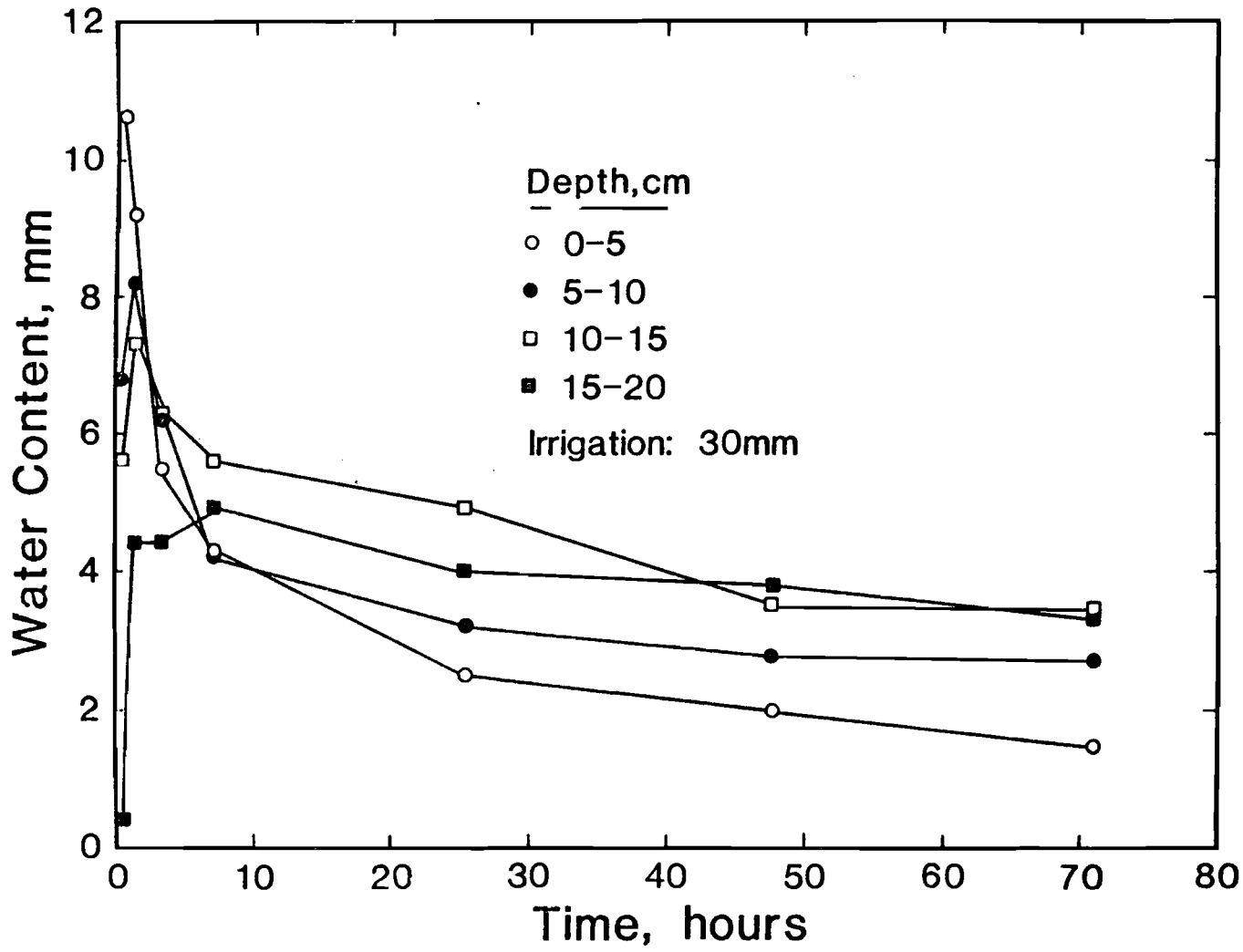

Figure 7. Surface zone drying patterns in goz sand. Noncrusted surface.

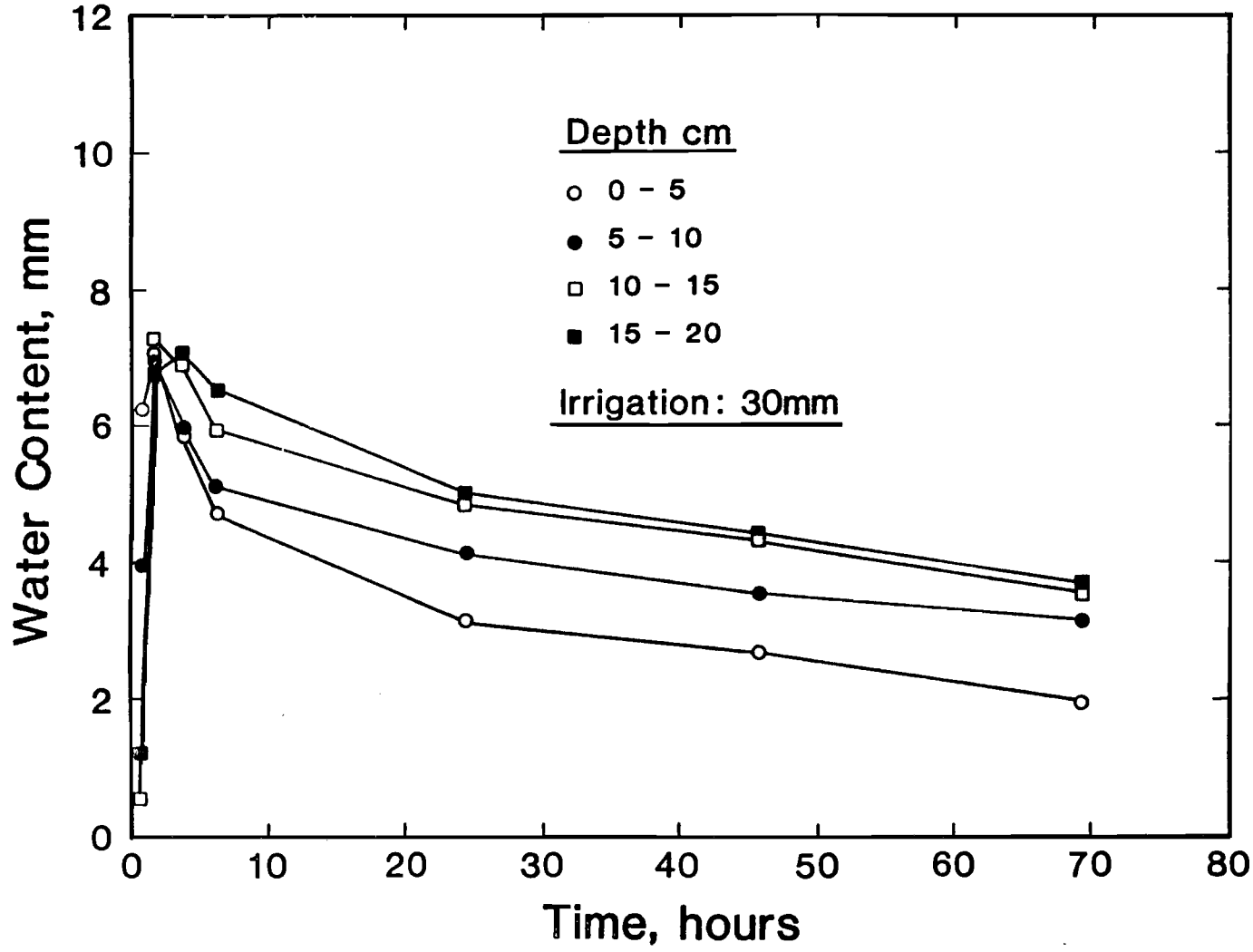

Figure 8. Surface zone drying patterns in goz sand. Crusted surface.

Profile Moisture Storage and Moisture Conservation: Measurements of profile moisture content as a function of depth and time began in early March 1985. Weekly moisture data were obtained at 15 cm depth increments down to a depth of 180 cm. All measurements were made by a neutron probe which was field-calibrated for the goz sand. The calibration curve along with the equation describing the curve is given in Figure 9. Typical moisture profiles for the crusted and noncrusted surfaces are shown in Figures 10 and 11, respectively. Data show extreme dryness near the surface, but an increasing moisture content with depth. The tendency for the moisture content is to continue to increase with depth, giving an impression that considerable amount of moisture may be present below the 180 cm depth. Moisture characteristic of the soil (see Figure 4) indicates that water is quite easily extractable at the observed wetness at lower depths. In fact, at the time of these observations, deep rooted plants such as sesame, pigeon peas, watermelon, and native bushes were found to be growing without apparent stress. It should be quite interesting to explore moisture distribution and root water uptake at depths considerably below the 180 cm depth. Observations reported here are consistent with the deep drainage discussed earlier. A knowledge of the depth to which the applied water reaches and what happens to it should lead to management strategies for a better utilization of goz sands.

Comparison of the moisture data for 7 March and 27 March (Figures 10 and 11) show that water loss from the profile is negligible. Total storage for the 180 cm profile is plotted as a function of time in Figure 12. Data show that, on an average, more than 116 mm of water was present in the soil profile through most of the dry months. The dry season rate of water loss averaged around 0.8 mm/week. These results are consistent with the strong mulching effect expected from rapid drying of the surface zone.

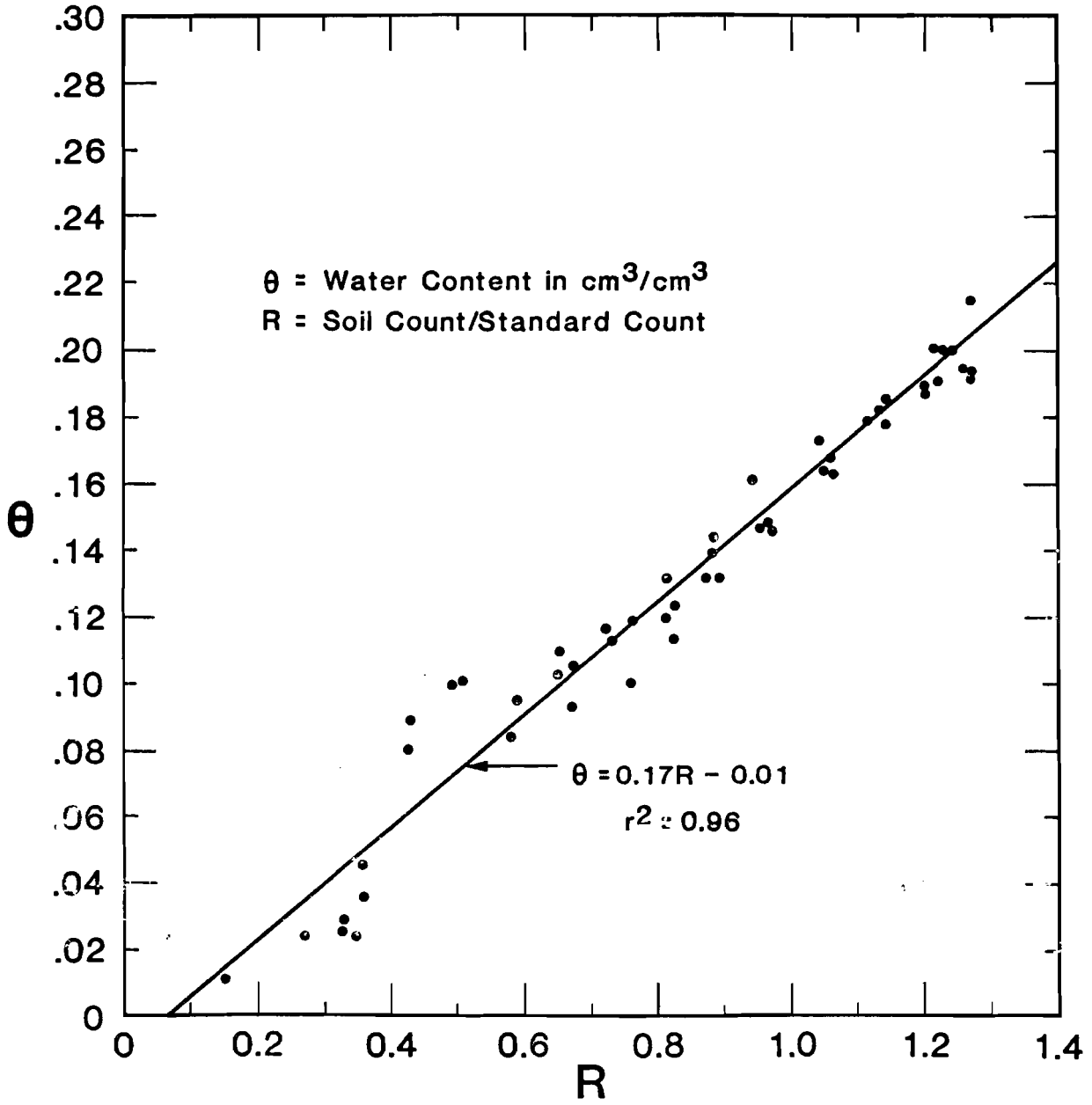

Figure 9. Neutron meter calibration for goz sand, WSARP, El Obeid.

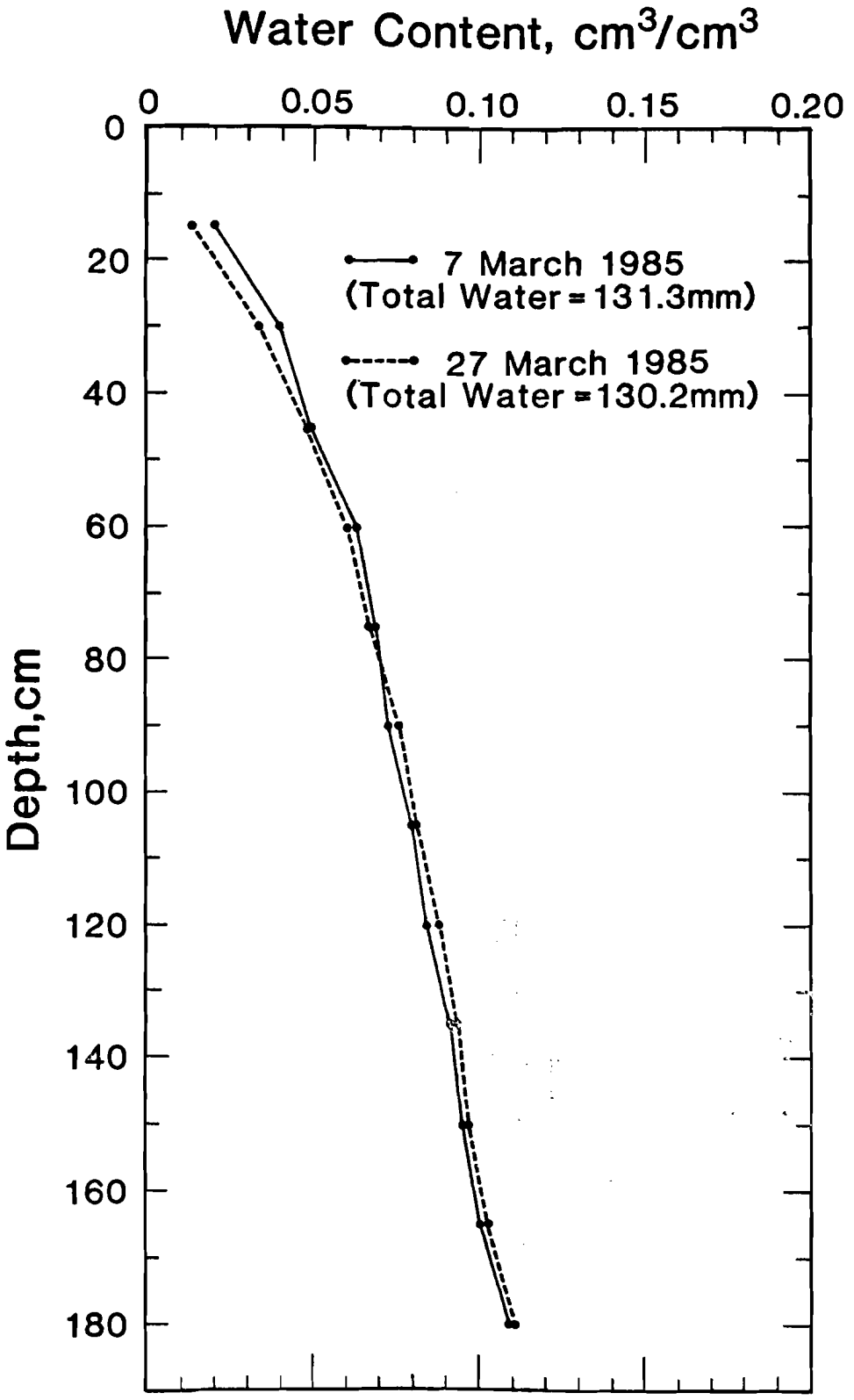

Figure 10. An example of dry season moisture profiles in goz sand. Crusted surface.

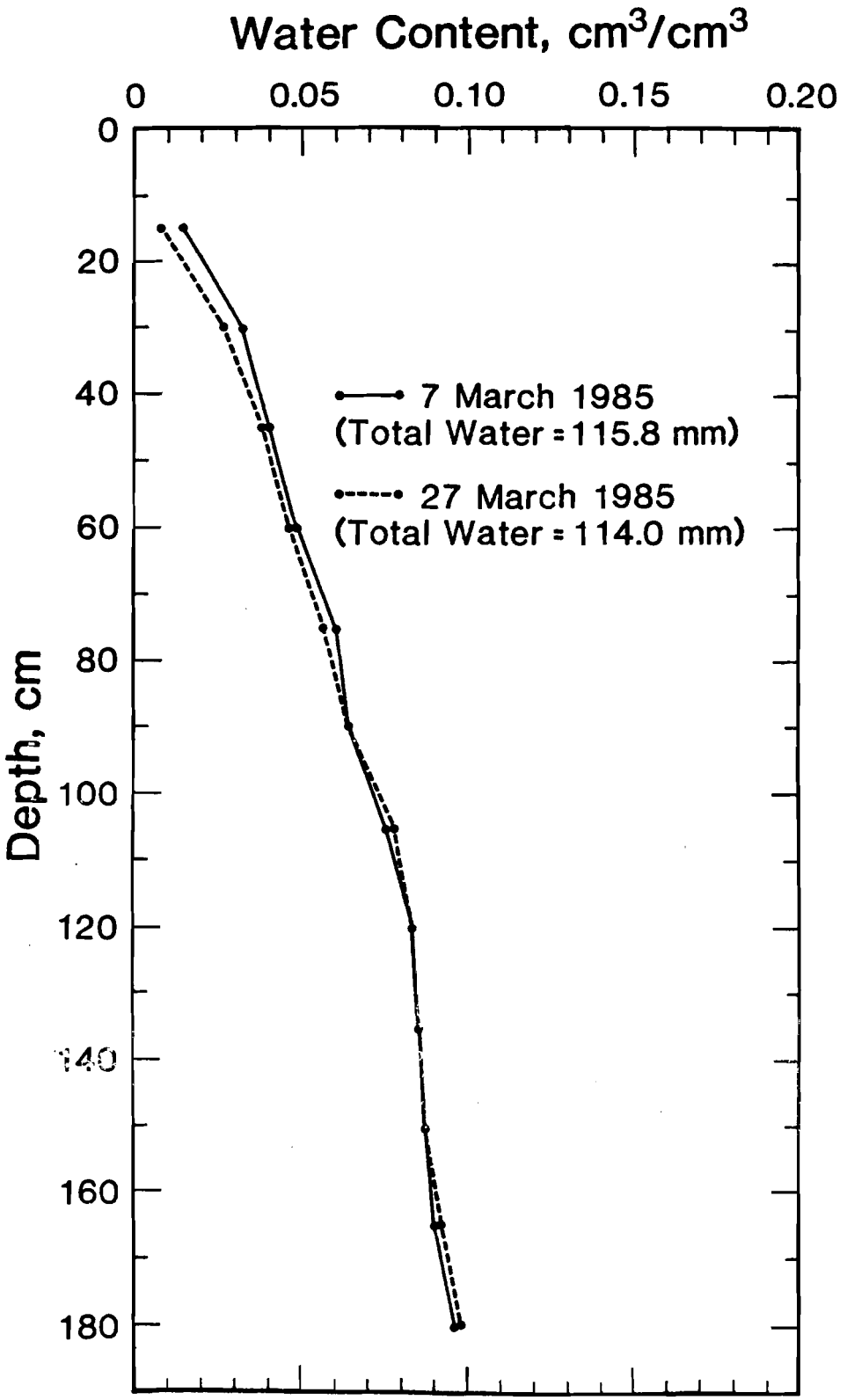

Figure 11. An example of dry season moisture profiles in goz sand. Noncrusted surface.

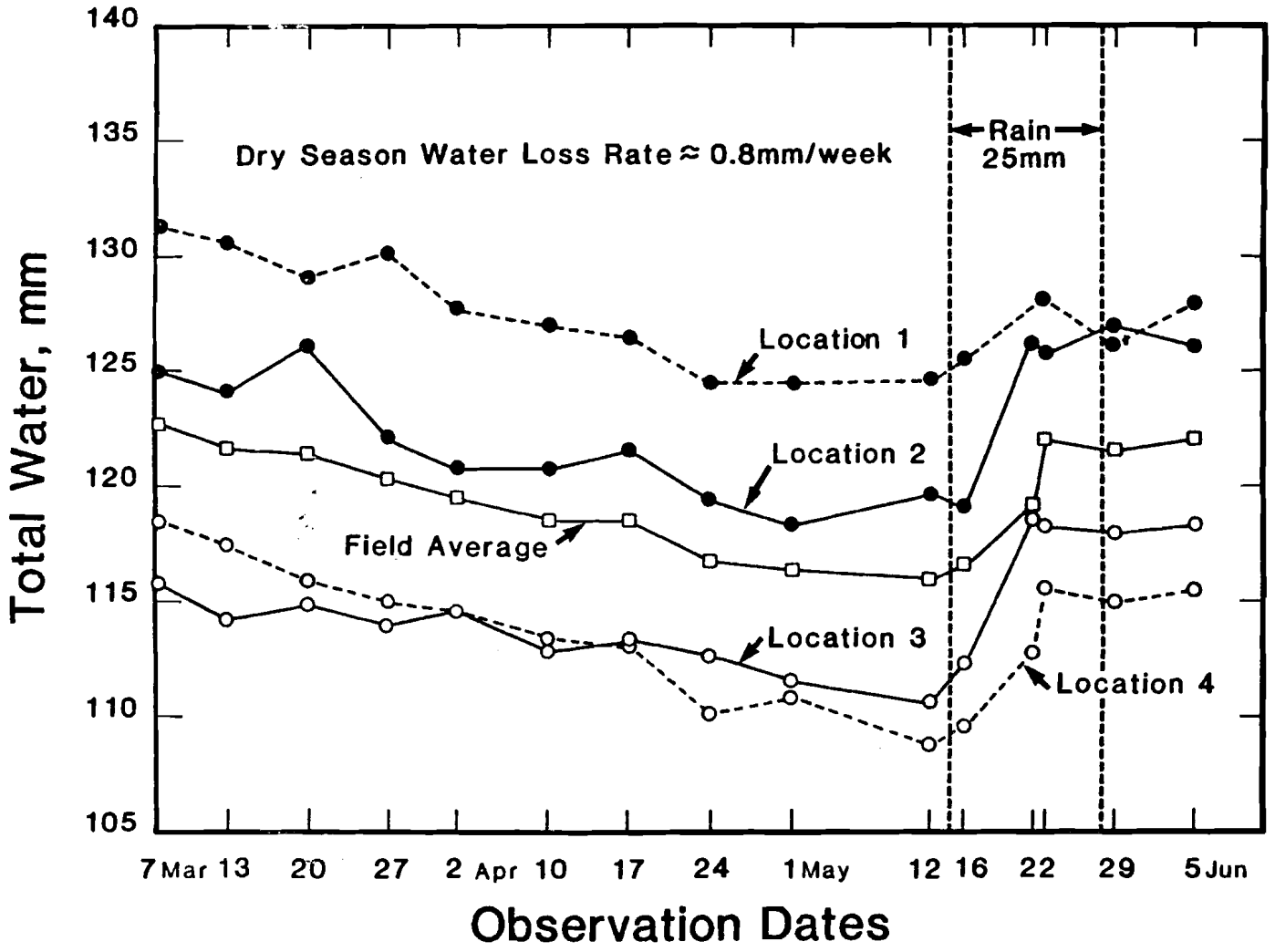

Figure 12. Dry season changes in the total water content of a 180 cm deep profile in goz sand. Locations 1 and 2: Crusted surface; Locations 3 and 4: loose sand on the surface.

An interesting fact emerges about water conservation in goz sands when we consider the balance between observed profile moisture storage, 1984 rainfall, water loss rates during the dry season, and possible crop water use during the 1984 cropping season. The 1984 rainfall was only 160 mm. The dry season water loss rates suggest that profile will have 110 mm of water at the end of June 1985, if no rain is received. If the 1984 rainfall was the only source of water, then the storage value at the end of June 1985 will suggest an accumulated loss of about 50 mm of water for the year. This is impossible, given that dry season water loss rates are about 1 mm/week, and crops were grown during the rainy season when evapotranspiration losses must have been considerably higher. It seems that a certain amount of moisture was conserved from the 1983 season or seasons before, and was available for crop use during the 1984 cropping season. It is also possible that a certain amount of moisture moved into the root zone from depths below the 180 cm depth.

If we can make estimates of the various components of water balance, an idea of the amount of conserved water from the previous season(s) can be obtained. We can use the following relationship.

$$S_1 + R - (ET)_c - (ET)_d = S_2$$

Where S_1 is the available water conserved from 1983 season, R, is the 1984 rainfall, $(ET)_c$ is the evapotranspiration during the 1984 cropping season (July to October), $(ET)_d$ is the evapotranspiration during the dry season (November to June), and S_2 is the stored water at the end of June 1985.

The rainfall, R for the 1984 season was 160 mm. Values for evapotranspiration during the cropping season, $(ET)_c$,

are unavailable for El Obeid. In other similar localities (1,2,3) millet water use has been reported to be about 300 to 400 mm. This would give an average value of 3.3 mm/day for growing seasons of 90 to 120 days. The millet stand in El Obeid was quite poor during the 1984 season. Consequently, we will assume a value of $(ET)_c$ only half as much. Then, for the period from July to October, the total $(ET)_c$ will work out to be 203 mm. The dry season evapotranspiration, $(ET)_d$, can be estimated from water loss rates observed for the dry months. Since there were no crops and the surface was dry, a water loss rate of 1 mm/week should apply for the months from November to June (see Figure 12). Thus, $(ET)_d$ will work out to be 35 mm. The stored water at the end of June 1985, S_2 is estimated to be 110 mm. Substituting all values in the water balance equation gives 188 mm as the value of S_1, the conserved water from 1983 season.

The analyses presented above is not rigorous because some of the components are based on estimates and water movement across the bottom boundary of the root zone was excluded. The amount of conserved water depends strongly on what is assumed as the value of $(ET)_c$ for the season. The value of $(ET)_c$ used in the present analysis is quite conservative. A liberal value will increase the computed value of the conserved water. Results, nevertheless, suggest that conservation of soil moisture in significant quantities is highly probable in goz sands. Rapid drainage and rapid drying of the surface zone provide the necessary conditions for moisture conservation.

DISCUSSION, EVALUATION, AND RECOMMENDATIONS

Rapid drainage and rapid drying of the surface zone stand out as the two most important hydrologic characteristics of goz sand. Post-irrigation moisture distributions (Figures 5 and 6) show that applied water moves down to deeper layers at a rapid rate and the amount of moisture retained in the soil does not exceed 50 percent of the maximum capacity suggested by porosity values. The implication is that, even if heavy rains are received, water content of the soil will not rise above a certain maximum set by the drainage characteristics of the soil. Rapid drainage would seem to be desirable, as the water moving to deeper layers is relatively better protected from evaporation. The undesirable aspect, however, is that water in the deeper layers is not easily available to shallow root systems.

Rapid drainage arises from preponderance of large pores. The force with which water is held in soil pores decreases as the pore size increases. As a result, large pores drain easily under the influence of gravity. The tension-water content relationship for goz sand (Figure 4) shows that a rather large portion of water retained in the soil is held at very low tensions. This implies that most of the water is easily extractable. Data presented indicate that small application of water at frequent intervals will, probably, be more effective for shallow rooted field crops. However, man has no control over the process unless irrigation is the means of water supply.

Rapid drying of the surface zone in goz sands (see Figures 7 and 8) has important consequences. A dry layer on the surface is a natural mulch which acts as a barrier against evaporation (4) and, thus, appears to be a desirable

feature. However, this is also the zone where seeds are planted. Surface zone moisture deficiencies adversely affect seed germination and seedling establishment. Seedling failure results in poor yields despite the fact that water is available in the lower depths of the soil profile.

Crusting was not expected in goz sands. But it does occur. Its adverse effects on seedling emergence were quite apparent during the 1984 cropping season. Additionally, the spatial variability was so great that none of the experimental results could be sensibly analyzed. The causes of crusting are not understood. It seems that a certain amount of fine silt or clay cemented between the coarse sand grains creates a rigid skeleton. The surface of the goz land normally appears rippled with undulations created by deposition of wind blown sand and silt around physical barriers such as plant residue, bushes, or previously existing mounds. In the event of a high intensity rain, surface runoff occurs from elevated surfaces into depressions created by the movement of sand. Although the runoff is temporary, it does bring fine silt (or clay) and deposits it between coarse sand grains left exposed by wind erosion. The above hypothesis is advanced on the basis of the observations that all crusted patches existed in depressions. Dr. Hassan Hag Abdulla* (personal communication) speculates that some sort of a microbial gum might be responsible for strong cementation of the sand grains. However, it is suspected that surface temperatures (55 C) prevalent in goz sands will not favor significant microbial activity.

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* Director, Soil Survey Administration, ARC, Wad Medani, Sudan

Seasonal water supplies from rainfall are not adequate to support an active vegetative growth of economic plants (see Tables 1 and 2). Conservation of moisture from season to season appears to be the chief mechanism of water supply for the native species. Conservation of rainwater is achieved through the combined effects of rapid infiltration, rapid drainage, and rapid drying of the surface zone. However, since much of the water stays at great depths, it cannot be effectively utilized by shallow rooted crop plants. The depth to which the rainwater drains down is unknown. Measurements of moisture distribution to a depth of 180 cm were made from early March through early June, the driest months of the year. Data (Figures 10 and 11) showed considerable wetness in the lower part of the profile. Moisture distribution curves showed a tendency for the moisture content to continue to increase with depth. It appeared as though considerable amount of moisture might be present at depths below the 180 cm depth. The upper part of the soil profile appeared to be very dry. It seems that, in absence of an effective crop cover, weed transpiration is the chief mechanism for water loss from goz soils. Water in the deeper layers of the soil profile is, probably, utilized by deep rooted species, mainly the scrub vegetation and acacia trees which normally grow in the region. Rainwater is effectively conserved in areas where there is lack or absence of active vegetative cover. Estimates, based on 1984 rainfall data and profile moisture measurements, indicated availability of a significant amount of conserved water for crop use during the 1984 cropping season. Measurements of total profile storage, as a function of time, showed that water loss rate did not exceed 1 mm/week through most of the dry months (Figure 12).

Goz sands are, thus, ideally suited for tree crops with deep root system. However, if cropping with field crops must go on, effective management practices will have to be

evolved. Management strategies will require an understanding of weather patterns (both long and short term), crop/weather interactions, and specific limitations due to soil physical behavior and hydrogic processes.

Data obtained during the 1984-85 season indicate that rapid establishment of seedlings and selection of deep rooted crops are the key to improving crop productivity in goz sands. Of the two, initial establishment of the crop would appear to be of overriding significance. Whatever the rooting characteristics of a plant, it must be first established before it can draw on moisture supplies in the deeper layers. Factors affecting seedling establishment are rapid drying of the surface zone and attendant increases in the mechanical strength of the soil in crusted areas. Data in Figures 2 and 3 show that penetration resistance on crusted surfaces rises sharply with drying of the soil. Penetration resistances encountered are of such magnitude that is quite restrictive to seedling emergence and root extension (5,6). Observations during the 1984 cropping season showed 100 percent failure in several plots where crusted surfaces existed. A quantitative estimate of the land area with crusting problem was not made. Visual observations, however, give the impression that crusted patches, probably, account for 30 to 40 percent of the land area. Transitions between crusted and noncrusted patches also occur.

Research is needed to evolve methods for seedling establishment in goz soils. The crusting problem can be dealt with by plowing the land to homogenize the soil. However, special measures will have to be taken to minimize the risk of wind erosion. Most of the crust strength appears to be confined to the top 3 to 5 cm of the soil (Figure 2). Removing this layer and exposing the soil below

should be helpful. Planting in ridge-furrow beds was one of the trials during the 1984 season (7). Although the plots were located in a crusted area, effect of crust was eliminated in the process of preparing the ridge-furrow beds. Millet seeds planted in furrow bottoms did not experience adverse effects of the crust. Ridge-furrow beds also appear to be a safer alternative from the erosion control point of view, since ridges minimize the effect of the wind (8). The only problem is that ridges in a sandy soil are not very stable. They tend to collapse when exposed to high intensity rains. Methods for stabilizing sandy ridges is a subject for research. Spraying the ridges with solutions of soil binding substances appears to be an attractive proposition but may not be feasible under conditions in Kordofan.

Effect of rapid drying of the surface zone is, probably, most severe on seed germination and seedling establishment. Data in Figures 7 and 8 show that rate of water loss decreases with depth. Therefore, if seeds are planted deeper, their chances of germinating should improve. However, emergence can be affected if seeds are placed too deep. This is particularly true for small seeds, as food supply is limited and emerging seedlings are too weak to provide the required force against the overlying soil. In a depth of planting trial (7), millet emergence and seedling survival were better for a planting depth of 10 cm than for planting depths of 5 or 15 cm. Results are reported in Table 5. Although moisture conditions at 15 cm depth were much better, the depth was too deep for millet seeds. Larger seeds such as those of groundnuts and pigeonpeas can be planted deep. Research is needed to determine the optimum depth of sowing for various crops under varying moisture regime.

Table 5. Effect of depth of planting on millet seedling emergence and survival in goz sand.

(Unreplicated Trial)

Planting depth	Observation dates						
cm	25 Jul*	28 Jul	30 Jul	31 Jul	1 Aug	4 Aug	7 Aug
	Emerged and surviving hills, %						
5	0	45.7	80.0	77.1	78.1	69.5	59.0
10	0	65.7	91.4	91.4	92.4	94.3	88.6
15	0	4.8	10.5	19.0	27.6	30.5	29.5
20	0	0	0	0	0	0	0

* Date of planting

Mulching had the most positive effect on crop establishment and yield. Results are given in Table 6. However, since mulching material is in short supply, it is doubtful that farmers will find the practice adaptable. The results, nevertheless, demonstrate usefulness of the ground cover. Loose sand on the surface had similar effect as mulching; however, the bare sand generally blew and caused sandblasting of young seedlings. The idea of residue cover may be modified to provide surface barriers to sand movement with minimal use of the residue. Cover crops, such as watermelon, may be planted in strips to minimize the effect of wind on sand movement.

Planting in ridge-furrow beds was also found to be effective (see Table 7). Ridges, apparently, reduced the effect of the wind and provided partial shading to young seedlings. Digging of the soil to prepare ridge-furrow beds also eliminated the effects of crusting. The only difficulty was that ridges were susceptible to damage by water in the events of high intensity rains. Research is needed on ridge design and methods to stabilize them.

Attempts were also made to treat the planted hills with evaporation retarding amendments (7,9). Success was obtained in pot tests (Figures 13 and 14), but field results were disappointing. This approach is still a subject for research. Efforts should continue to examine locally available materials and to develop the technical aspects of treating the sand with amendments.

Dry seeding of millet is a common practice in North Kordofan, but success depends on timely arrival of rainfall and sustained availability of moisture after emergence. Farmers practice dry seeding only by intuition. A study

Table 6. Effect of mulching on millet growth and yield in goz sand.

Treatment	Plants	Tillers	Heads	Biomass, kg/ha		Grain[2]
	No/ha	No/ha	No/ha	Fresh	Dry[1]	kg/ha
Mulch	18839	79770	54306	2216	1662	108
No Mulch	17847	48072	24653	765	620	59

Number of hills planted: 26667/ha

1. F-test showed significant difference at 5% level, CV = 25.0%

2. F-test showed significant difference at 5% level, CV = 14.0%

Table 7. Effect of seedbed preparation and planting technique on millet growth and yield in goz sand.

Treatment	Plants	Tillers	Heads	Biomass, kg/ha		Grain[2]
	No/ha	No/ha	No/ha	Fresh	Dry[1]	kg/ha
Traditional	17963	67078	31296	1224	812	62
Seed Cradle	4259	29022	14630	854	506	50
Ridge-Furrow	8241	49211	37685	1588	962	102

Number of hills planted: 26667/ha

1. F-test showed no significant difference at 5% level, CV = 57.4%

2. F-test showed no significant difference at 5% level, CV = 68.0%

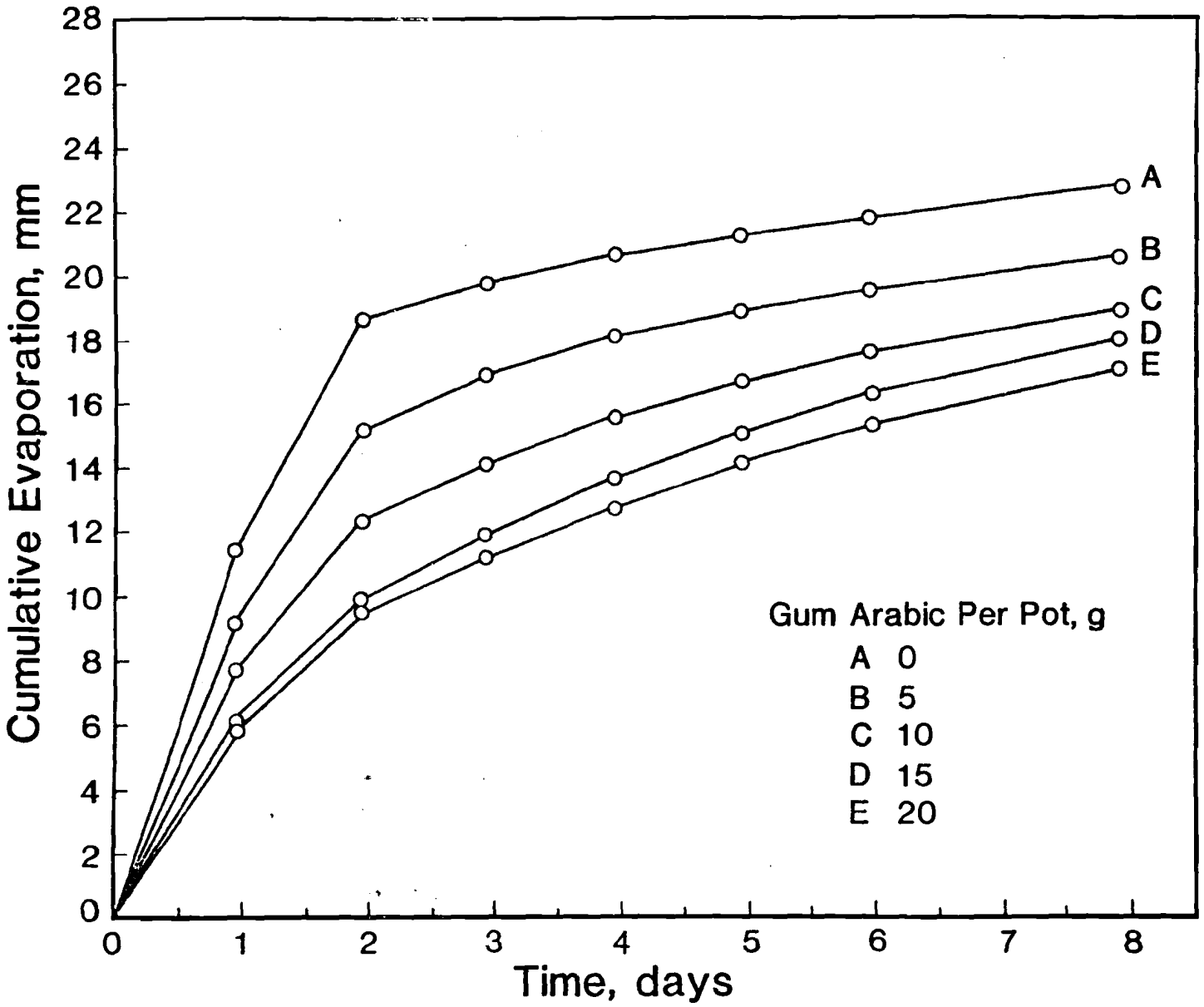

Figure 13. Effect of gum arabic on evaporative loss of water from potted goz sand.

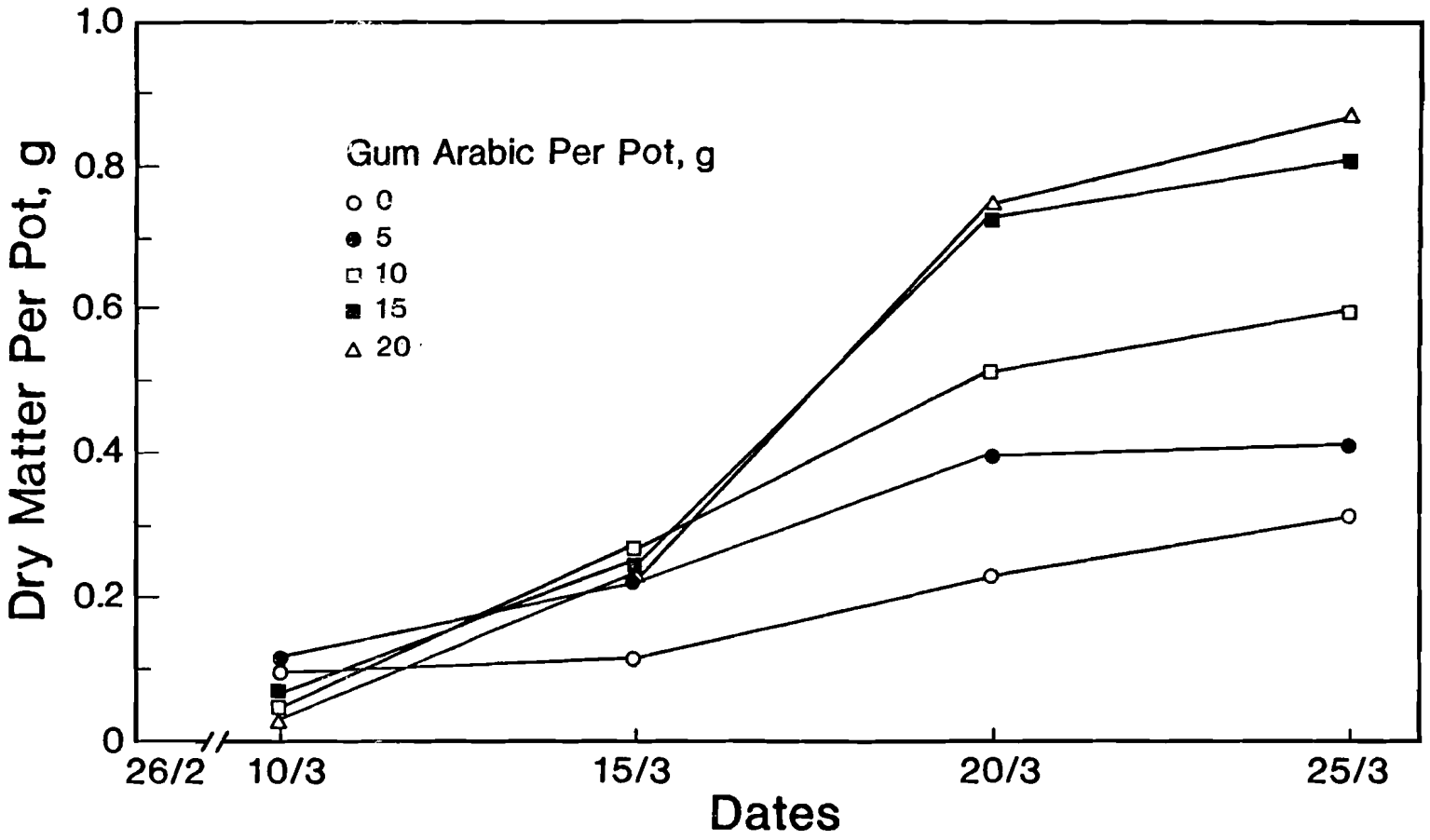

Figure 14. Sorghum seedling dry matter production in potted goz sand, as affected by gum arabic treatment of the soil.

needs to be made of the crops which can be dry seeded and farmers need to be advised on the best schedule to follow. Studies made elsewhere in the sahelian/Sudanian zone (2) indicate that dry seeded millet will not germinate until it receives approximately 6 mm of rain in one shower. Also, a small amount of rain, such as 6 mm must be followed by additional rain if the millet crop is to survive. Rainfall or moisture stored in the soil must supply approximately 1.5 mm/day for the first 20 days and 3 mm/day for the subsequent 10 days. These conditions do not correspond to maximal water needs of millet but permit the crop to survive. Similar studies need to be made in Western Sudan, not only for millet but also for other crops. Agroclimatological information such as dependable rainfall and evaporative demand, and a knowledge of soil moisture storage and depletion patterns are necessary inputs to making time of planting decisions.

Seedling establishment depends on whether or not seedling roots are able to extend into the moister zone before the drying of the surface zone becomes limiting. Most seeds take 3 to 4 days to emerge under optimum moisture conditions. This period is, probably, too long for the surface zone moisture conditions in the goz sand to remain favorable for germination and seedling root growth. If this period can be reduced, the chances of seedling survival will improve. Planting soaked seeds appears to be an effective means of reducing the germination and emergence time. Trials should be carried out to determine the effect of seed soaking on rate of emergence and seedling establishment. The idea can be extended to cover most crops of interest. Moisture conditions under which soaked seeds do best should be investigated. Optimum time of soaking is also a subject for research.

A combination of seed soaking, deep planting, and time of planting relative to the first significant rainfall appears to have the potential for best results.

An interesting discussion took place between Dr. Tarake Berhe of INTSORMIL, Dr. James J. Riley, and myself. The question was whether millet can be transplanted as seedlings in goz sand. The idea had emerged from considerations of factors that limit seedling establishment. First, we know from drying patterns, that deep placement of seeds is advantageous because of slower rate of drying. However, small seeds cannot be placed too deep because of limited food supply and difficulty in emergence through the overlying soil. But a seedling, on the other hand, can be planted deep because it is already developed. Second, limiting moisture conditions in the surface zone, most probably, develop at a faster rate than the rate of seed-planted seedling root extension. This disadvantage can be overcome by placing pre-emerged seedling roots in the moist zone. The catch is that we do not know if millet is a crop that can be transplanted or whether some water will have to be applied to the newly transplanted seedlings. Will the plant breeders be interested in this problem? We calculated that it would take approximately 70 gallons of water to raise seedlings enough for a 1 hectare field. Another advantage is that healthy seedlings can be selected and transplanting can be carried out when enough rainfall has accumulated. A plastic lined pit of several hundred gallon capacity can be prepared in the field to accumulate runoff. This water can be used for initial watering of freshly planted seedling, if needed.

The above idea remained only an idea. It was never discussed with anyone for the fear that it might be ridiculed. However, since this report consists of only

untested or partially tested ideas, the idea of transplanting millet is included for those who might view it as something worth trying. The idea can be extended to other crops as well.

In addition to the problem of seedling establishment, selection of deep rooted crops must be given serious consideration. Moisture profile data for goz sand (Figures 10 and 11) reveal that a substantial amount of water stays at lower depths and is easily extractable (Figure 4). This implies that deep rooted crops have a better chance for survival and production. Genotypes of the presently grown crops must, therefore, be selected based on their root growth. However, since the net effect of root growth is on moisture extraction, selections should be carried out based on water extraction patterns. Those genotypes that are able to extract water from deeper layers must be selected. An alternative would be to change crops. Millet is not a very deep rooted crop. Sesame, watermelon, pigeonpeas, and kerdadi are known to be deeper rooted than millet. Sesame and pigeon peas were observed to be growing on the WSARP farm during the March/April months, without much stress. A corroborative evidence of moisture availability in deeper layers comes from the observations of healthy growth of scrub vegetation species which are also known to be deep rooted.

Regardless of what success is achieved in terms of improving seedling establishment or selection of deep rooted crops, actual yields will depend on potential water supplies that are available for crop evapotranspiration. Even if 300 to 350 mm rains are received per season, the supply may not be adequate for a reasonable yield. Some of the rainwater will definitely be lost to nonuseful losses such as very

deep drainage, weed transpiration, and direct soil evaporation. At least some of the water retained in the soil profile will remain unextractable. Water use efficiency for millet in the Sahelian Africa seldom exceeds 3 kg/ha/mm water (3). If we assume 700 kg/ha as a reasonable grain yield then the crop must evapotranspire 233 mm of water. But whether or not any grain yield is produced will depend on how the extractable water is evapotranspired. If much of the water is used for vegetative growth, little will be available for the reproductive phase. Plant population must, therefore, be adjusted to available water supplies for evapotranspiration. When number of plants increases, competition for available water also increases. During the 1984 cropping experiments at the WSARP Farm, plots with high plant population and vigorous early growth failed, almost totally, later in the season. It is, therefore, important to make an assessment of the available moisture supplies and determine what plant population can be adequately supported. This would require several years of field experiments on plant population and water use.

Fortunately, rainwater is effectively conserved in goz sands. Estimates based on 1984 rainfall data and profile moisture measurements indicated a significant amount of conserved water. Fallowing of land, therefore, might be an effective means of augmenting root zone moisture storage from season to season. Fallowing suggested here is different from the bush-fallowing practices in Western Sudan. A land rotation system is envisioned in which a block is planted to crops only once every three years. An effective weed control is a must for the land being fallowed. However, measures must be taken to minimize the risk of wind erosion. A cover of dead residue is most effective. Alternatively, the surface of the land to be fallowed may be turned into a ridge-furrow bed.

Measures must be taken to combat wind erosion. Rapid moisture loss and wind erosion are serious problems in goz sands. Windbreaks have long been proposed as one of the solutions. However, since moisture is limited, windbreak plants planted in the required density and geometry fail to establish. Observations show that there are certain species (names unknown to the author) of the scrub vegetation which remain green and grow without stress even during the driest months. These plants must be very deep rooted and must be physiologically adapted to the drought conditions. At present these plants are growing at random. It is proposed that seeds from these species be collected and planted in the desired density and geometry. Methods of moisture conservation must be applied to help in the initial establishment. Initial watering may be necessary to ensure establishment of young seedlings. It may also be useful to investigate the means of rapid propagation of natural desert species. Planting density must be carefully considered for there may be a danger of mutual competition.

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