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Effect of an Asphalt Barrier on Water Storage and Drought Probability[1]

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ABSTRACT

Field measurements of water redistribution after infiltration were made on two sandy soils with and without asphalt barriers at a 55 cm depth to determine the barrier effect on soil water potential gradients and on water retention at various times. Estimates of the effect of the barrier on seasonal drought severity and on movement of water to horizons below the barrier were made on one of the soils.

Soil water potential gradients and the volumetric water content at different depths were nearly the same for barrier and nonbarrier plots on Hubbard loamy coarse sand because a coarse sand-gravel layer between the 25 and 50-cm soil depths acts as a water barrier. After 96 hours drainage, suctions in Zimmerman fine sand reached 31 cm of water just above the barrier and 61 cm at the same depth without barrier. Available water to barrier depth was increased from 2.9 cm to 7.5 cm by the barrier.

Available water above the barrier was determined for Zimmerman fine sand and was used to calculate the effect of a barrier on drought probability. This analysis showed that on barrier plots, there would be 25 fewer drought days in the driest year in 10, and 31 fewer in the 5 driest years in 10.

Based on rainfall at the Zimmerman fine sand site, it was shown that, over a 3-year period, supplemental water needed to keep an active growing crop could have been reduced by 58% with a barrier. Probable water loss by percolation, on the other hand, would have been one-fifth as great with a barrier as without.

Additional index words: **Sandy soils, Layered soil, Drainage barrier, Nutrient percolation.**

THE flow and retention of water in soils can be altered by interrupting soil homogeneity with a nearly continuous layer of a material of markedly different properties. Erickson, Hansen, and Smucker (1968a) showed that asphalt could be spread as a liquid to form a continuous barrier under sandy soils and thus interrupt water movement.

Hammond, Lundy, and Saxena (1967) found that a well-formed asphalt barrier could markedly reduce the final infiltration rate of highly permeable soils thereby tending to decrease the loss of water from the root zone by deep percolation. Field studies also showed that an asphalt barrier increased the amount of water retained in the soil above a barrier by 40% at "field capacity" (Hammond et al., 1967) to 53% after 3 days of drainage (Erickson et al., 1968a).

Asphalt barriers may substantially reduce the volume of irrigation required to maintain a satisfactory water regime. For example, Erickson et al. (1968b) found that sugarcane grown on barrier plots did not require irrigation for the first 5 to 6 months of the growing season and in the entire season received only 90 mm of irrigation water compared to 281 mm required by the control plots. Similarly Hansen and Erickson (1969) found that there was a saving of 3.8 cm of water when potatoes and beans were grown on barrier plots. Their barriers were established by excavation and asphalt spraying or by prototype equipment used to spray the asphalt.

The objectives of the study reported herein were to obtain additional data on soil water storage on sandy soil types, to estimate the reduction in irrigation required, and to assess the effect of a barrier on movement of water into deeper horizons. In addition, an attempt has been made to determine the effect of the barrier on drought probability. The hydraulic properties of the barrier have been considered (Palta, Blake, and Farrell, 1972) and crop yields effects will be dealt with in a future paper.

MATERIALS AND METHODS

Asphalt barriers were installed at a depth of 55 cm on two soil types in the spring of 1968 using commercially available equipment that laid overlapping strips 229 cm wide each pass. Hot asphalt emulsion sprayed at the rate of 14,000 liters/ha gave a layer of asphalt with a mean thickness of 1.4 mm. This infiltrated the soil while still hot, resulting in a barrier thickness of about 3 mm. Barrier plot size was 30 × 30 m on Hubbard loamy coarse sand and 23 × 30 m on Zimmerman fine sand.

Soil Description. Since the barrier gave different effects in the two soils studied, some descriptive detail of their characteristics is warranted. Hubbard loamy coarse sand is an Udorthentic Haploboroll. A dark gray upper A and a gray-brown lower A horizon grade into a coarse sand B horizon. The coarse sand texture continues into the C horizon. Gravel fragments mostly 2 to 5 mm in size, comprising up to 20% of the coarse sand layers, are found below 22 to 40 cm either dispersed in the matrix or as strata. Zimmerman fine sand is an Alfic Udipsamment. This soil has a very dark gray loamy fine sand A1 horizon, dark brown loamy fine sand A2, yellowish brown fine sand B2 horizon and a pale brown fine sand horizon with yellowish red loamy fine sand bands at depths of 75 to 150 cm. The C horizon is a fine sand extending to several meters in depth.

Infiltration and Water Redistribution. Water was ponded to a depth of 10 cm for 20 hours in diked plots 4.5 × 4.5 m for estimating infiltration rate. Water was kept in the borrow pits around the dikes of each plot throughout the period of wetting and measuring of the infiltration in order to minimize the lateral flow component. Water supply to the plots was cut off, and the depth of water was recorded at 15-min intervals. From the arithmetic mean of three independent measurements of water depth for four time intervals, the basic intake rate of barrier and control plots was measured. Infiltration measurements were not made on Zimmerman fine sand.

After ponding with 10 cm of water, a record of suction changes with time was made at 10 cm depth intervals beginning at the time water left the surface. Soil water pressure potentials were observed and added to gravity head using the soil surface as datum. These measurements were continued until changes in suction with time became very small. This time was about 90 hours for Hubbard loamy sand and 140 hours for Zimmerman fine sand. In order to minimize evaporation, the surfaces were covered with an organic mulch.

Effect of Barrier on Drought Probability. The extent to which barriers would reduce drought frequency, or reduce irrigation requirement, was estimated for Zimmerman fine sand. Use was made of data of Blake et al. (1960) who calculated drought probabilities based on rainfall at the same location for the 25-year period, 1932-1957. Through a bookkeeping procedure, calculating evapotranspiration by the Penman method (1948), they summed up the monthly number of drought days, i.e. days in which the supply of available soil water was exhausted. Using their data we plotted drought days against water storage capacity to depth of the barrier for barrier and non-

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barrier plots at several probability levels. From this plot, we derived the monthly and seasonal number of drought days for the two treatments on Zimmerman fine sand.

Supplemental Water Requirement and Percolation Losses. Tensiometers in field plots during the growing season showed that less frequent irrigation was required under a barrier because of the increased water retention. However, difficulties in irrigation scheduling and distribution on many randomly located plots did not allow careful measurement of possible savings in supplemental water.

In order to estimate the maximum possible savings in irrigation and in probable percolation losses below the root zone, a model was considered for Zimmerman fine sand for the 3 years, 1969 to 1971. A daily water balance was calculated for each year from May 1 through August 31, a reasonable growing season for many vegetable crops at this location. Components in the accounting were 1) an assumed stored water quantity on May 1 each year equal to the measured storage capacity to a depth of 55 cm, 2) a rooting depth of 55cm, 3)evapotranspiration calculated by Penman's method (1948), 4) rainfall as measured at the site, 5) supplemental irrigation of 1.8 cm each time 0.6 of the stored water was depleted, 6) assumed loss to the plants by percolation of water in excess of the upper limit of storage, and 7) negligible runoff, a reasonable assumption for highly permeable, essentially nonsloping soils.

RESULTS AND DISCUSSION

Infiltration Rate and Water Redistribution

Mean final infiltration rate on Hubbard loamy coarse sand was found to be 3.2 cm/hour for plots underlaid by barrier and 5.1 cm/hour for plots without a barrier. These rates are relatively high in both cases. But it is clear that movement is slowed by the barrier. Hammond et al. (1967), using 15 cm diameter cylinders in a 1.3 m diameter flooded area, found 8.2 and 19.7 cm/hour respectively for Lakeland fine sand. They calculated an apparent hydraulic conductivity of 1.73 cm/hour through the barrier.

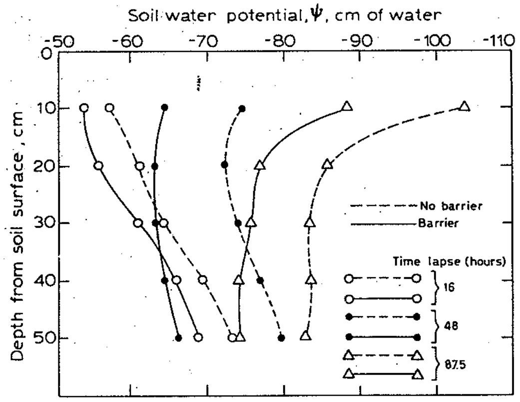

Fig. 1. Changes in soil water potentials with depth at various times after infiltration in Hubbard loamy coarse sand.

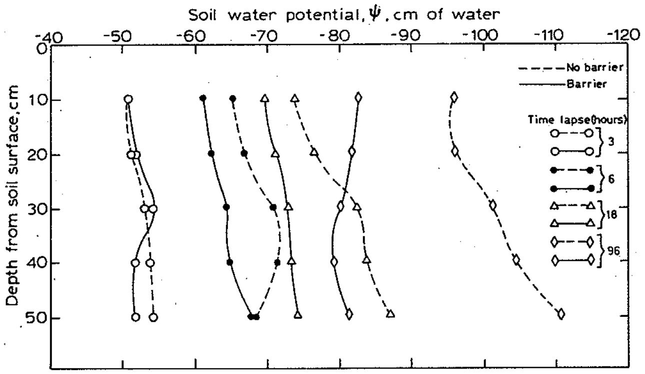

Fig. 2. Changes in soil water potentials with depth at various times after infiltration in Zimmerman fine sand.

In field plots on Hubbard loamy coarse sand and Zimmerman fine sand a record of suction changes with time was made beginning with the time water left the soil surface (zero time). Figure 1 shows the soil water potentials. It is clear from this figure that the curves for barrier and nonbarrier plots run almost parallel to each other at any given time showing similar gradients during drainage. Although the nonbarrier plot had slightly higher suction than the barrier plot at all times, differences were small, suctions at 50 cm depth being 24 and 32 cm H_2O for barrier and nonbarrier plots, respectively, at 87.5 hours (74—50=24 and 83—50=33). The shape of the potential-depth curve at 87.5 hours indicates that water movement in surface layers was towards the soil surface.

In contrast, in Zimmerman fine sand (Fig. 2) water was still moving downward at the end of 96 hours in the nonbarrier plot. On the barrier plot practically no water was moving; i.e. there was no potential gradient at 96 hours. Further it is also evident from Fig. 2 that at this time the suction at 50 cm depth, just above the barrier, was 31 cm of water compared to 61 cm for the nonbarrier plot at the same depth. Even though potential evaporation from a bare surface was calculated to be 2.6 mm per day, virtually all of the water movement was downward, indicative of the more complete surface cover than on Hubbard loamy coarse sand.

The barrier was more effective in increasing water retention in Zimmerman fine sand than in Hubbard loamy sand. The reason for this result is shown in the profile description. The coarse sand-gravel layer at the 25 to 50 cm soil depth in Hubbard behaves as a barrier in interrupting downward movement. In contrast to the Hubbard profile, Zimmerman is a soil whose texture is uniform with respect to depth. In this case the asphalt barrier breaks the continuity of the profile and thus helps in storing more water than in a continuous profile.

The fact that effectiveness of a barrier varies according to the profile characteristics is further evident from the data presented in Table 1. It is clear that the volumetric water content in Hubbard loamy sand was little greater in the barrier than in the nonbarrier plot. In Zimmerman fine sand there was a marked differences between barrier and nonbarrier plots. Futhermore there was little change in water content with depth above 55 cm for the nonbarrier treatment, while there was an increase in water content with depth above the barrier (55 cm) for the barrier treatment. In the case of Hubbard loamy sand, mean-

Table 1. Water contents, percent by volume, in Hubbard loamy coarse sand and Zimmerman fine sand 90 and 140 hours after flooding, respectively.*

Depth, cm	Hubbard Loamy Course Sand		Zimmerman Fine Sand	
	Barrier	No Barrier	Barrier	No Barrier
0- 5	18. 53	18. 45	14. 00	11. 93
5-15	19. 55	19. 07	17. 77	12. 87
15-25	20. 61	20. 01	16. 70	12. 61
25-35	17. 33	16. 94	18. 72	12. 43
35-45	11. 44	13. 67	25. 28	11. 62
45-55			29. 15	13. 07
55-65			20. 41	19. 57
65-75			23. 58	25. 39

* Each observation is an average of three determinations. Barrier depth was 55 cm.

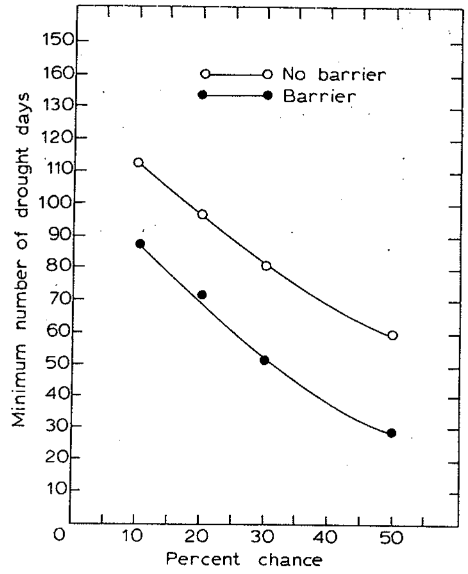

Fig. 3. Percent probability of having at least the number of drought days per season shown (assumed rooting depth, 55-cm).

ingful samples could not be taken at depths greater than 45 cm because of the coarse gravel layer.,

Effect of a Barrier on Drought Probability

Available water was calculated for Zimmerman fine sand by subtracting the 15 bar percentage of 7.1 from the water contents shown in Table 1. It was found that water retained in a 55 cm profile was 7.5 cm in the barrier plot compared to 2.9 cm in the nonbarrier plots. Thus the barrier more than doubled the water available to plants.

Using the available water contents to barrier depth of barrier and nonbarrier plots, minimum number of drought days per month at various probability levels was calculated. The data presented in Fig. 3 assume a root zone depth of 55 cm. A barrier reduces the probable number of drought days in all months and at all probability levels. In the driest 5 years out of 10, one would reduce the minimum number of drought days per season from 59 to 29 days at an assumed rooting depth of 55 cm (Fig. 3). It is seen in Fig. 3 that, depending on the probability level chosen, the number of drought days in a season can be reduced by 25 to 31 days using an asphalt barrier.

Table 2. Calculated supplemental water needed and percolation losses on Zimmerman fine sand with and without asphalt barrier.

Month	Precipitation cm	Barrier Irrigation cm	Barrier Percolation cm	No Barrier Irrigation cm	No Barrier Percolation cm
		1969			
May	3.2	0	0.1	5.3	0.4
June	9.7	5.3	0	5.4	4.0
July	13.6	1.8	0.8	7.1	7.5
August	0.3	5.4	0	8.9	0
Totals	26.8	12.5	0.9	26.7	11.9
		1970			
May	10.4	0	1.7	3.6	5.3
June	13.1	0	5.9	7.1	9.5
July	6.1	5.3	0	7.1	1.4
August	7.7	3.6	0	7.1	3.0
Totals	37.3	8.9	7.7	24.9	19.2
		1971			
May	7.4	0	0	3.6	3.6
June	9.7	0	0	7.1	3.8
July	4.9	5.3	0	7.1	0.9
August	7.8	5.4	0	7.1	3.5
Totals	29.8	10.7	0	24.9	11.8

The drought day concept must not be construed to mean that plants use water at a constant rate until "available" water depletion and thereafter have no water at their disposal. Rather, as moisture depletion is approached, plants can continue to preserve living tissue and can tolerate a few drought days even though it may be at the expense of yield or quality. The growth of roots into unexplored soil during this period as well as use of small amounts of water retained at suctions greater than 15 bars also acts to mitigate against complete collapse in growth. Crops like corn or wheat that have considerable drought tolerance during large parts of their growth cycles will undoubtedly benefit from reduction of the number of drought days.

Asphalt Barrier, Supplemental Water Needed and Leaching Losses

It is clear that if the soil water reservoir is increased, the irrigation required in a subhumid climate is decreased. Also, because rainfall is unpredictable, there is greater probability of seepage losses from precipitation if the reservoir is small than if it is large.

In order to determine irrigation water required and leaching losses of water, assuming optimal efficiency in use and timing of irrigation, an accounting was made for 3 years assuming a barrier and nonbarrier on Zimmerman fine sand. The procedure and assumptions are detailed under Methods.

Results of this accounting are shown in Table 2. On this soil type and under the climatic conditions of each of these years an asphalt barrier could save more than half of the water needed to keep plants adequately supplied. And this saving would be accompanied by a reduction in the loss of water to layers below the barrier.

Precipitation in each of the 3 years is shown in Table 2. Long-term means for the area are 8.9, 11.4, 8.5, and 9.9 cm for May to August, respectively. Thus it is seen that precipitation was normal in amount in 1970 with reasonably normal distribution by month. In 1969 and 1971 amounts were less than normal. However, barriers could reduce irrigation water needed around 60% in all years.

Seasonally, percolation of water could have been reduced with the barrier by 60% in 1970 as shown in Table 2. In the two drier-than-normal years it would have been reduced to near-zero. The concomitant risk of loss of fertilizer or other soluble substances would also be greatly reduced. Even if only part of this potential reduction in percolation and in water needed by irrigation is realized, it would be an important advantage for barriers.

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