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WATER MOVEMENT RESTRICTION BY PLANT RESIDUES IN A SILT LOAM SOIL *

by

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Fertilization and improved management practices in recent years have generally increased crop production. Where large quantities of straw, stover or other residues are plowed under, questions arise as to what effect these may have on moisture transmission and air-water relations in the soil. Partial severance of capillary contact between surface and subsoil by barriers of plant residues may have a profound influence on soil moisture relations until these materials decay sufficiently to re-establish contact.

The increase in the use of minimum tillage practices in production of corn raises questions as to the effects of large quantities of shredded cornstalks turned under with little fitting of the loose soil over the heavy barrier of litter. Also the manner of turning the materials into the soil may affect the results. If the furrow slice is turned on edge the effect may be somewhat different than with complete inversion.

It is the purpose herein to report some results from a laboratory soil model designed to get some fundamental information that would be difficult to obtain by field experimentation.

METHODS AND PROCEDURE

Silt loam soils are dominant throughout the midwestern United States. Hence, a silt loam surface soil (Mexico series) from McCredie, Missouri, was used to simulate the 'plow layer' and a loessal silt from Wilton, Missouri, was used for the 'sub-soil' material. These soil materials were used since considerable information on their physical properties has been obtained in previous studies. The model consisted of 6 columns of soil contained in cells 110 cm high and 30.5 by 7.6 cm in horizontal cross section. One wall of each cell was of clear plastic to permit observation during packing or wetting the soil. Except for the clear plastic the inside wall surfaces were coated with asphalt paint to waterproof the joints and dusted with silt to reduce wall-transmission of effects. Rubber gaskets were used to seal the joints between the clear plastic and edges of the end wall of each cell. A small opening between the base and the clear plastic wall allowed air to escape as water entered the soil surface. Polyethylene plastic sheeting spread over the opening on the inside before packing the soil columns prevented evaporation loss from the base.

Loessal silt was passed through a 1 mm screen to remove lime concretions and mixed to provide a uniform 'subsoil' material. The moisture content was adjusted to about 17.4 % or about 0.5 atmosphere suction. To accomplish this the silt was first moistened by stirring it in a thin layer on a concrete floor while adding water from a fine spray nozzle. The material was then allowed to dry while being stirred frequently. A 100-gram sample was taken for moisture every hour during the drying process.

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These were spread in a thin layer in a tray and dried in a forced draft oven for 30 minutes. When the results showed the moisture content was near the desired value, the silt was placed in a metal drum and covered with a plastic sheet for about 24 hours. Several soil moisture tube samples were then removed from the drum to determine the value to be used in subsequent calculations. This material was then packed in 5 cm layers to a bulk density (D_b) of 1.4 gm/cc and a depth of 95 cm in all the sections. Shredded cornstalks at the equivalent rate of 6 tons of dry matter per acre (5440 kg/ha) were placed on 4 of the sections. The cornstalks were spread evenly over the silt surface of two sections and over 3/4 of the surface of the other two. Screened Mexico silt loam surface soil was packed to a bulk density of 1.3 and a depth of 15 cm on top of the silt and/or the cornstalks on one of each pair of the sections and the same amount was placed loose on each of the others. The moisture content of the surface was adjusted to 22.4 % (about 0.5 atmosphere suction) before packing in the same manner as used with the silt. This moisture condition may be considered near the wet limit of the plowing range (1).

Mercury tensiometers were mounted on one wall of the model with the porous cells inserted into the soil through holes drilled in the wall. The tube connections of the cells were inserted through one-hole rubber stoppers which were used to seal the openings from leakage or evaporation loss. The cells were placed horizontally at 2 cm above and at 8, 18, and 38 cm depths below the loessal silt surface. The temperature in the laboratory was controlled at 22.0 ± 0.5° C.

The soil surface was covered with a piece of towelling and water applied to each column to a depth of 2 cm above the surface from a constant level burette until 10 cm of water had been applied. The total time for complete entry of the water into the surface of each column was observed and the average intake rate calculated. The wetting front positions at various time intervals were marked on the clear plastic wall of the columns. Tensiometer readings were made each day after the application of water. From the tensiometer readings and height positions the hydraulic gradients and direction of flow could be determined as drainage and evaporation progressed. Also from the readings and the moisture-release curve, changes in the air-water volume status of the surface soil were determined for the different treatments. Several test runs were made. On one the effects of making a second 10 cm application 14 days after the first were determined.

CALCULATIONS

To estimate the moisture transfer rates across the various contact or barrier conditions, duplicate columns were sampled at 7 and 29 days after water application. From differences in water content for the duplicates the average flow rates were determined. From charts of the hydraulic head with soil depth each day the direction of flow across the contact boundaries could be determined. The change from downward to upward direction of flow across the contact boundaries occurred between the fourth and sixth day for the various treatments. The average flow rates across the boundaries during the later period were small in comparison with earlier drainage flow rates.

The first moisture samples were taken one to three days after the time of reversal in flow direction. It was assumed that the upward flow rates during this short interval were about the same as the average estimated from the two moisture samplings. The errors involved in this assumption are small since the flow rates would be small near the time of reversal of flow direction. At this time the low pressure gradients would favor low rates of flow in comparison with the more rapid downward flow during and shortly after water was applied. From the assumed rates of flow for the short time intervals between the first sampling and the reversal of flow direction, the amounts found below the boundaries were corrected. From the corrected values the downward flow rates and conductivities were calculated. The values reported here are averages for the time and soil depth intervals given.

The average hydraulic conductivity was computed from the generally accepted relationship (3).

$$K_h = \frac{v}{i}$$

where v is taken as the average rate of flow and i is the average hydraulic gradient in the direction of flow. If v is expressed in cm/sec and i in cm of water per cm, then K_h is in cm/sec. If the average hydraulic gradient is expressed in ergs/gm, then the average hydraulic conductivity is given by

$$K = K_h/g$$

where g is the acceleration due to gravity. The dimension of K is time. For flow in unsaturated soil, K_h (or K) is not constant for a given soil, but varies with moisture-suction changes in the soil (2).

RESULTS

The average intake rates for the various treatments are shown in Table 1. For the first 10 cm application of water the initially loose soil absorbed the water more rapidly than the compacted. The cornstalk barriers did not reduce intake except where the soil surface was moderately compacted.

TABLE 1. *Average Intake Rates for Different Contact Boundary Conditions Tested.*

Contact Boundary Conditions		Water Applications**	
Soil Surface	Contact Barrier*	First 10 cm cm/hr	Second 10 cm cm/hr
Initially loose	None	8.0	1.7
Initially loose	75 %	8.9	1.7
Initially loose	Full	10.1	1.7
Moderately compact***	None	4.2	1.7
Moderately compact	75 %	2.5	1.8
Moderately compact	Full	1.3	0.5

* Nature of soil-silt contact: no barrier, full soil-silt contact; partial barrier and full barrier, 75 % and full contact severance by shredded cornstalks at 6 tons dry matter per acre (5440 kg/ha).

** Second 10 cm application 14 days after first.

*** Soil surface layer (15 cm) compacted to bulk density of 1.3 gm/cc.

Where the surface soil was initially loose, it settled upon wetting to about the same density as the compacted treatments. The rates for the second application were lower and more nearly the same. There is no doubt that residual effects from the first application were partly responsible for the results. The partial- or full-barrier treatments would be drier in the surface 14 days after the first application than those with full contact. The effect of the barrier on intake would be partially offset by a drier soil surface. It is noteworthy that the lowest intake rate was for the initially compacted soil having full barrier at the contact. Thus, moderate compaction of the soil above the barrier appears to reduce rather than accelerate flow of water into the soil.

Wetting front advance was consistent with the intake rates. The front had advanced down to about 10 cm below the contact level for all three initially loose treatments after 0.5 hour. The front in the moderately compact no-barrier treatment was at about 8 cm below the contact. The front in compact partial- and compact full-barrier sections had just passed through the contact into the loessal silt at this time. The differences in advance were progressively less with time. After 34 hours the wetting front positions for all the barrier treatments were at about 55 cm and those for the no-barrier treatments were at about 60 cm below the contact level.

The calculated air-space percentages for the soil layer (5 cm) just above the contact boundary are shown in Figures 1 and 2 for the first 10 cm application of water. For the initially loose soil the air-filled porosity was critically low for only a few hours. The full barrier evidently did restrict flow after the larger voids were drained. Rapid increase in air-space for this treatment after about 50 hours can be attributed to severance of capillary contact with the subsoil and loss of moisture from the surface by evaporation. Where the soil was initially compacted to a bulk density of 1.3, the air-space remained critically low for the barrier treatments for 5 to 10 hours after the application. Thus moderate compaction of the surface soil seemed to increase rather than decrease the isolating effect of the plant residue barriers.

Since the results for the initially loose and moderately compacted surface soil were similar for the second application the results for air-space percentages are shown only for the compacted soil (Figure 3). The air content was critically low for more than ten hours for the no-barrier, for more than 15 hours for the partial-barrier and for more than 50 hours for the full-barrier condition. Even after 14 days of drainage and drying there were residual effects from the first wetting. These were probably due in part to biological activity in the cornstalks with some plugging of the voids in the soil near the barriers.

The average flow rates and hydraulic conductivities for the contact interval and also the upper layer of silt below the contact were determined. The results for the period when the hydraulic gradient and flow through the contact were downward are shown in Table 2. Note that the average gradient is many times greater in the contact one than below it. The hydraulic head values just below the contact were estimated by extrapolation of hydraulic headdepth curves from the upper tensiometer level in the silt to the top of the silt layer (Figure 4). The values obtained were consistent with the moisture determinations at sampling. The moisture content of samples in the upper (0—5 cm) layer of silt was about the same as that in the next interval below (5—10 cm). On the other hand the samples taken from the interval above the contact were somewhat drier (in terms of equivalent suction). It is clear that the greatest change in hydraulic gradient usually occurred near the contact boundary. Only in the short time interval during which flow reversed from downward to the upward direction across the contact boundary would the gradient at the contact be little different than in the body of silt below or in the soil above.

The average hydraulic gradients in the contact interval above the silt

TABLE 2. *The Effects of Shredded Cornstalk Barriers and Soil Compaction on Downward Movement of Moisture into a Silt Loam Soil.*

Transmission Terms	Surface Soil Treatments					
	Initially Loose			Moderately Compact*		
	Contact Barrier**			Contact Barrier**		
	None	Partial	Full	None	Partial	Full
	Average flow through boundary interval (2 cm)					
v, 10^{-7} cm/sec.	315	226	221	204	132	127
i, cm/cm	15.8	25.0	23.5	19.1	29.3	23.5
K_h, 10^{-7} cm/sec.	19.9	9.0	9.4	10.7	4.5	5.4
	Average flow through upper silt layer (1 cm)					
v, 10^{-7} cm/sec.	289	207	201	186	119	115
i, cm/cm	3.0	2.0	2.0	2.0	1.5	1.5
K_h, 10^{-7} cm/sec.	96	104	100	93	79	77

* Initially compacted to bulk density of 1.3 gm/cc.

** Nature of soil-silt contact: no barrier, full soil-silt contact; partial barrier and full barrier, 75 % and full contact severance by shredded cornstalks at 6 tons dry matter per acre (5440 kg/ha).

during downward flow were a little higher with than without the cornstalk barriers (Table 2). Since the average downward rates of flow across the boundaries were also lower with cornstalk barriers present, the hydraulic conductivity values were lower.

The average flow rates and hydraulic conductivities for the upward movement of moisture across the contact intervals and the silt layer below the boundaries are shown in table 3. Note that the average gradients are much greater in the contact zone than below it. Although the gradients

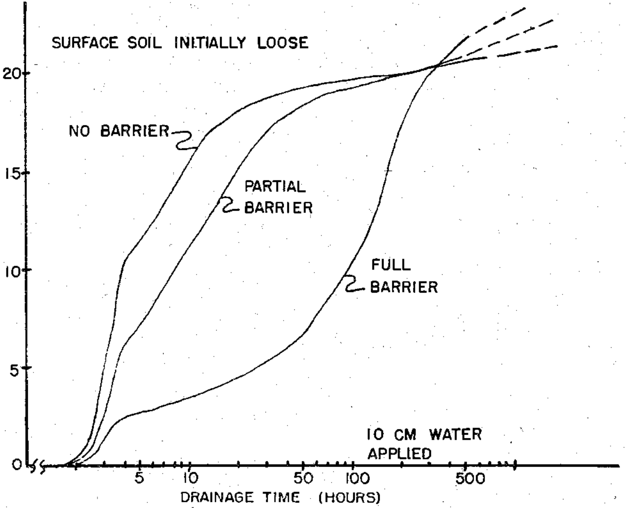

Figure 1. The changes in calculated air-space percentages with time after the first 10-cm application of water for the treatments with initially loose surface soil.

TABLE 3. *The Effects of Shredded Cornstalk Barriers and Soil Compaction on Upward Movement of Moisture Due to Evaporation at the Soil Surface.*

Transmission Terms	Soil Surface Treatments					
	Initially Loose			Moderately Compact		
	Contact Barrier			Contact Barrier		
	None	Partial	Full	None	Partial	Full
	Average Flow Through Boundary Interval (2 cm)					
v, 10^{-7} cm/sec.	15.5	10.8	6.7	11.3	8.0	6.1
i, cm/cm	86	296	526	77	456	635
K_h, 10^{-7} cm/sec.	0.18	.036	.013	0.15	.018	.010
	Average Flow Through Upper Silt Layer (1 cm)					
v, 10^{-7} cm/sec	15.2	10.1	5.6	10.9	7.2	5.1
i, cm/cm	5.6	3.6	2.4	3.0	1.9	1.73
K_h, 10^{-7} cm/sec.	2.7	2.8	2.3	3.6	3.9	2.9
	Average Total Loss from Profile					
v, 10^{-7} cm/sec.	18.9	17.9	16.4	16.6	16.3	17.1
	Average Proportionate Loss from Surface Soil					
v, 10^{-7} cm/sec.	3.7	7.8	10.8	5.7	9.1	12.0

were increased somewhat by cornstalk barriers, they were high across soil to silt contacts with no cornstalks. The initial compaction of the surface soil seemed to reduce rather than increase contact through the barrier. It is interesting that the rate of evaporation loss from the total profile (surface soil plus silt) was not appreciably affected by the cornstalk barriers. The greater proportionate rate of loss of water from the surface soil above the barriers than that in capillary contact with the silt will account for this. Partial isolation of the surface soil retained more moisture in this layer so that total evaporation losses from the surface were about the same for the measurement period. If measurements had been made for a still later period after the surface had dried, the barriers would doubtless have reduced total loss from the soil.

CONCLUSIONS

It is evident that during unsaturated flow hydraulic gradients in the contact zone between different types of porous materials may be somewhat greater than in the materials themselves. Even with a silt loam soil in contact with a loessal silt the estimated values were often large. Such differences may exist between a plowed layer and the untilled subsoil immediately below. The presence of plant residues in the contact zone may further increase hydraulic gradients and the degree of isolation of two soil layers.

Moderate compaction, such as resulting from harrowing or rolling, may not improve contact between soil layers through a plant-residue layer. In fact, moderate compaction reduced the rate of flow across a cornstalk barrier, especially during drainage from the surface soil into the silty subsoil material. Movement of soil particles from loose surface soil into a relatively

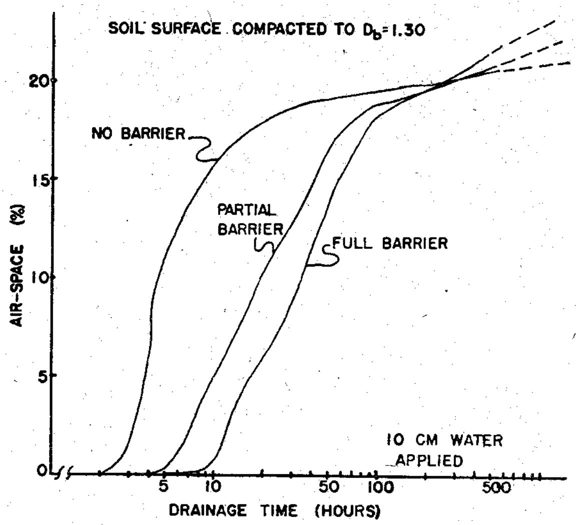

Figure 2. The changes in calculated air-space percentages with time after the first 10-cm application of water for the treatments with the surface soil initially compacted to 1.30 gm/cc.

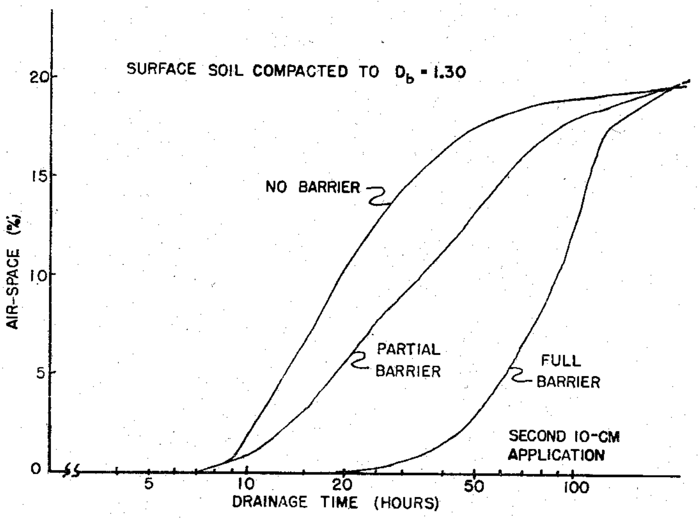

Figure 3. The changes in calculated air-space percentages with time after the second 10-cm application of water (14 days after the first). Surface soil initially compacted to 1.30 gm/cc.

loose mat of plant materials during drainage may be more effective in establishing contact than compacting the soil above the barrier.

The hazard of poor aeration during wet weather due to isolation by a trash barrier may be reduced by turning a furrow slice on edge so as to achieve partial contact between the plow layer and the subsoil. The critical

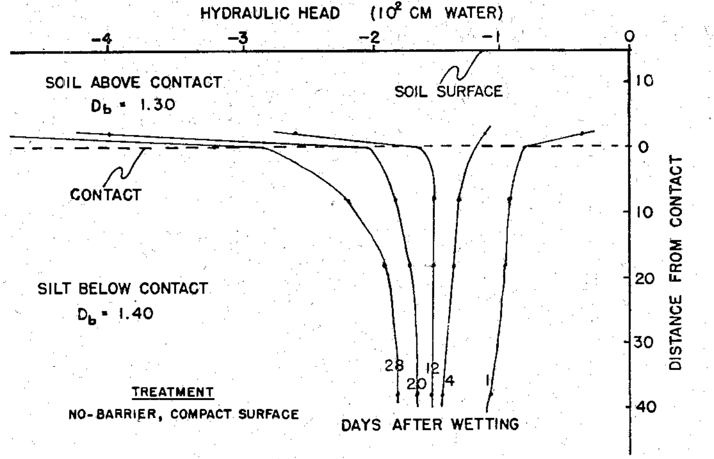

Figure 4. The changes in hydraulic head with soil depth below the contact and with time after a 10-cm application of water to the surface.

period of low air-content in the surface soil after wetting may be greatly reduced with as little as 25 % soil to subsoil contact (Figures 1, 2 and 3). However, the average reduction in flow rates across the boundaries by a trash barrier during drainage and drying of the soil appears to be roughly proportional to the amount of contact severance by the barrier.

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SUMMARY

Soil models were used to study the transmission of moisture across barriers formed by turning under plant residues. After a heavy application of water the air-filled porosity of Mexico silt loam was very low only a short time where the surface was initially loose. If compacted to 1.3 gm/cc the time was increased. The presence of a shredded cornstalk barrier further increased the time of low air content. Hydraulic gradients in the contact zone between surface and subsoil was usually greater than in the soil body. This was increased by plant residues severing contact. Moderate compaction of the soil surface reduced flow across the barrier at low suctions. The average reduction in conductivity across the boundary by a trash barrier was much greater at high than at low suctions.

RÉSUMÉ

Des 'modèles' de sol ont été utilisés pour étudier la transmission de l'humidité à travers les barrières que constituent les débris végétaux enfouis. Après application d'une forte dose d'eau, le volume total des pores remplies

d'eau d'un limon (Mexico silt loam) ne restait très bas que pour un temps relativement court quand au début de l'expérience sa surface était meuble. Quand celle-ci avait préalablement été compactée à 1.3 gm/cc, ce temps était plus long. Cette période de faible teneur en air était encore prolongée par la présence d'une barrière constituée de paille de maïs hachée. Le gradient hydraulique était généralement plus grand dans la zone de contact entre la couche superficielle et le sous sol que dans le restant du profil. Ce phénomène s'accentuait encore là où des résidus végétaux interrompaient le contact direct entre les deux couches. Une compaction modérée de la surface diminuait le passage d'eau à travers la barrière sous l'influence de faibles suctions. La diminution moyenne de cette conductivité pour l'eau à travers la limite précitée, causée par cette barrière de déchets végétaux enfouis, était beaucoup plus grande pour les hautes valeurs de suction que pour les basses.

ZUSAMMENFASSUNG

Zum Studium der Wasserdurchlässigkeit durch Versperrungen, aus eingegrabenen Pflanzenresten gebildet, wurden bestimmte Bodenmodelle benutzt. Nach einer tüchtigen Wassergabe war die lufterfüllte Porosität von Mexico-Schlufflehm nur kurze Zeit sehr niedrig dort wo die Oberfläche anfänglich lose war. Wenn auf eine Dichte von 1.3 g/cc zusammengepresst, wurde die Zeit verlängert. Die Gegenwart einer Hemmungsschicht von zerfaserten Maisstengeln verlängerte deutlich die Zeit eines geringen Luftgehaltes. Hydraulische Gradienten in der Kontaktzone zwischen Oberfläche und Untergrund waren gewöhnlich grösser als im Bodenkörper. Durch Pflanzenreste welche den Kontakt erschwerten, wurden sie verlängert. Mittelmässige Zusammendrückung der Bodenoberfläche verminderte die Wasserströmung durch die Barrière bei niedrigem Ansaugen. Die mittlere Verringerung der Leitfähigkeit durch die Grenze einer Pflanzenabfallschicht war viel grösser bei hohen als bei schwachen Absaugungen.

DISCUSSION

M. DE BOODT: I want to point out that a barrier, even if it is of manure or of lime, has a large practical influence. In Belgium, during a dry summer, 1959, when the manure was not mixed through the soil, by lack of biological activity due to dryness, the drop in wheat yields was 10—20 per cent.

V. C. JAMISON: I agree, certainly the isolating effect of a trash barrier increases as the soil gets drier. I might add that under some conditions such a barrier may be beneficial, especially if plants have roots penetrating and ramifying the subsoil before the surface dries. Water may be conserved under some conditions.