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MOVEMENT OF CARBON DISULFIDE VAPOR IN SOILS AS AFFECTED BY SOIL TYPE, MOISTURE CONTENT, AND COMPACTION

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MOVEMENT OF CARBON DISULFIDE VAPOR IN SOILS AS AFFECTED BY SOIL TYPE, MOISTURE CONTENT, AND COMPACTION[1, 2]

H. A. HANNESSON[3]

INTRODUCTION

THE INVESTIGATION of the movement of carbon disulfide vapor in soils was undertaken by Hagan[4]. This study is a continuation of Hagan's work. He devised and reported the method, and presented sample data on Yolo soils. This paper involves soils in six series in both the dry and the moistened conditions. It deals with compaction in a more practical way than did Hagan's paper. It gives more complete data on the effects of high and low soil moisture on permeability to carbon disulfide vapor. And it compares soils of similar texture in different soil series in both the dry and the moist condition.

Carbon disulfide vapor, being extremely toxic to plant life even at relatively low concentrations, has been used extensively as a herbicide, particularly in controlling such deep-rooted perennial weeds as wild morning-glory (*Convolvulus arvensis* L.). Although in most instances it has proved effective, the results are sometimes unsatisfactory. The purpose of this study is to throw more light on the factors that influence the behavior of carbon disulfide when injected below the surface of the soil.

Being a gas at ordinary temperatures, carbon disulfide moves throughout the soil. Several factors determine its distribution: differences in partial pressure of the gas from place to place in the soil, soil texture and structure, compaction, moisture content, and soil temperature. In addition, the soil has the capacity to sorb, or take up, carbon disulfide vapor. Obviously, under field conditions these factors must be considered together, because all act interdependently to condition the over-all behavior of the vapor in the soil. Since the numerous factors involved in the open field are beyond control, the study has been conducted under laboratory conditions. Although the natural soil is disturbed by removal from the field, the problem has been somewhat simplified by using laboratory procedures.

Since liquids and solids can sorb some gases and vapors, or can form new compounds with them, two processes influence the movement of carbon disulfide vapor in the soil: sorption, tending to hold the chemical and restrict movement; and diffusion, tending to move it. Since the method used in these studies measured the net movement of vapor after sorption had come to equilibrium, diffusion alone was involved. A study of sorption as a process distinct from diffusional movement is contemplated at some future date.

[1] Received for publication January 28, 1944.

[2] This investigation was inaugurated and directed by the Division of Botany, College of Agriculture, under their weed-control project. The work was supported by funds contributed to the California Agricultural Experiment Station by the Wheeler, Reynolds, and Stauffer Chemical Company.

[3] Research Assistant in Botany; resigned August, 1941.

[4] Hagan, R. M. Movement of carbon disulfide vapor in soils. Hilgardia 14(2):83–118. 1941.

METHODS AND SOILS USED

Briefly, the method consisted in measuring the amount of carbon disulfide vapor that diffused through a soil column in a given time when one end of the column was subjected to saturated vapor and the other kept free of vapor by moving air. The total pressure of gases in and around the soil remained constant; the partial pressure of carbon disulfide vapor varied from saturated for the operating temperature to approximately zero. The vapor was concentrated at the lower end of the column; upward movement was measured after diffusion through the column reached a steady state. All experiments were conducted at controlled temperatures. Values obtained were used to calculate the permeability of the soil. For further details of the method, see Hagan's paper[5].

Data will be discussed for several important soils occurring in the Sacramento and San Joaquin valleys of California. These soils have been derived from sandstones and shales, basic igneous, granitic materials, mixed alluvium, and organic materials.[6]

Yolo Series.—The Yolo soils are formed of transported materials derived originally from sandstones and shales, with minor mixtures from other sources. The flood plains and confluent fans occupied by these soils make up broad alluvial plains. The soils have been rapidly built up by the deposition of alluvial material in the valleys by minor streams. Weathering is relatively slight. The reaction is nearly neutral; the organic-matter content is low; and if the soil is tilled when wet, a plow sole is readily formed. The surface soil is brown, being darker than the subsoil. The entire profile is without structural development. The soils have high water-absorbing and water-holding capacities.

Hanford Series.—The soils of the Hanford series are formed from well-mixed transported material from granitic sources, carried by streams to the valleys and deposited as broad confluent fans and flood plains. The surface soils are brown to light brown, highly micaceous, generally gritty, devoid of profile development, low in organic matter, and neutral in reaction.

Fresno Series.—The material from which the Fresno soils are derived has been transported from granitic sources and deposited as nearly flat plains, rather poorly drained. Weathering under these conditions, the soils have a definite lime hardpan of irregular thickness, which occurs generally within a depth of 30 to 60 inches from the surface. The surface soils are gray to brownish gray, rather shallow, more or less calcareous, and basic in reaction; the subsoils are more alkaline and calcareous. To depths of 4 to 10 inches the surface soils are very porous and break up into granular tilth. In places the salt content is high.

Salinas Series.—The Salinas soils, formed from mixed alluvial material, occupy low terraces and stream-valley plains. The surface soils to depths of 12 to 24 inches are dark grayish brown, friable, and rather easily maintained in good tilth. The subsoils are heavier-textured and somewhat lighter-colored than the surface, with lime accumulation from place to place.

[5] Hagan, R. M. Movement of carbon disulfide vapor in soils. Hilgardia 14(2):83–118. 1941.

[6] Shaw, C. F. Some California soils and their relationships. Univ. of California Syllabus JD: 1–117. (Mimeo.) 1937.

Aiken Series.—The Aiken soils occur widely in mountain and foothill regions of the Sierra Nevada, the Cascade Range, Trinity Mountains, and Coast Ranges, occupying gentle to steep slopes. They are derived from basic igneous rocks, primarily andesites or basaltic lavas. The surface soils are brownish red to reddish brown, granular, soft in consistency to depths of 4 to 10 inches, and usually slightly acid in reaction. The subsoils are deep red and of heavier texture than the surface; they break up into soft to firm clods or lumps, coated with brownish-red colloid.

Stockton Series.—The Stockton soils are derived from mixed transported material, mainly from basic igneous rocks. They occupy basinlike flat or gently sloping plains, on which water accumulates during the rainy seasons.

TABLE 1

SOIL PERMEABILITIES AS INFLUENCED BY TEXTURE

Soil series and texture	Moisture content		Permeability units*	
	Dry	Wet	Dry	Wet
	per cent	*er cent*	$K \times 10^{12}$	$K \times 10^{12}$
Yolo series:				
Fine sandy loam	3.1	17.9	9.70	1.20
Loam	3.6	22.0	8.10	1.10
Clay	5.8	31.3	6.70	0.80
Salinas series:				
Fine sandy loam	3.1	16.9	8.40	1.89
Clay	8.9	30.5	6.95	1.51
Hanford series:				
Fine sandy loam	2.1	17.7	7.60	3.75
Loam	3.6	19.6	7.40	2.78

* The permeability unit has been defined as the gram-poises per cm^2 per second per millimeter of mercury difference in partial pressure per cm.

An impervious substratum underlies these soils, which are already of low permeability. The surface soils to depths of 10 to 15 inches are dark gray to black, usually heavy-textured, and of an adobe structure. When wet they are plastic and sticky, but when dry they crack and shrink to large blocks with wide cracks between them. On secondary cracking they break up into granular or small-lump structure. They are high in colloidal organic material and are basic in reaction, though noncalcareous. The subsoil is heavier-textured than the surface soil, is highly calcareous in its lower part, and rests abruptly on a yellowish or brownish sandy clay substratum, more or less rocklike.

EXPERIMENTAL DATA

In this study factors that bear most directly on the use of carbon disulfide as a herbicide have been emphasized.

Texture.—In table 1 are presented data for several textures: air-dry[7] samples were compacted to an apparent density of about 1.20 grams per ml. The highest flow of carbon disulfide is obtained in the fine sandy loams, the lowest in the clays; and an intermediate flow in loams. When these same soils

[7] The terms "dry" and "wet" as used in this paper refer to approximately an air-dry condition, and to a water content near the moisture equivalent. Tables 1, 2, and 3 give the moisture contents of soils reported.

are moistened to nearly their moisture equivalents the permeabilities, though very low, are again highest in the fine sandy loams and lowest in the clays.

A similar textural relation was found to hold at both higher and lower compaction values as well. One must bear in mind, when appraising the effect of texture on the permeability of soils to carbon disulfide, that it becomes difficult to separate the effect of the inherent structural characteristics.

Compaction.—In tillage operations, soils may be compacted by the application of forces normal to the soil surface (compression), or by the combination

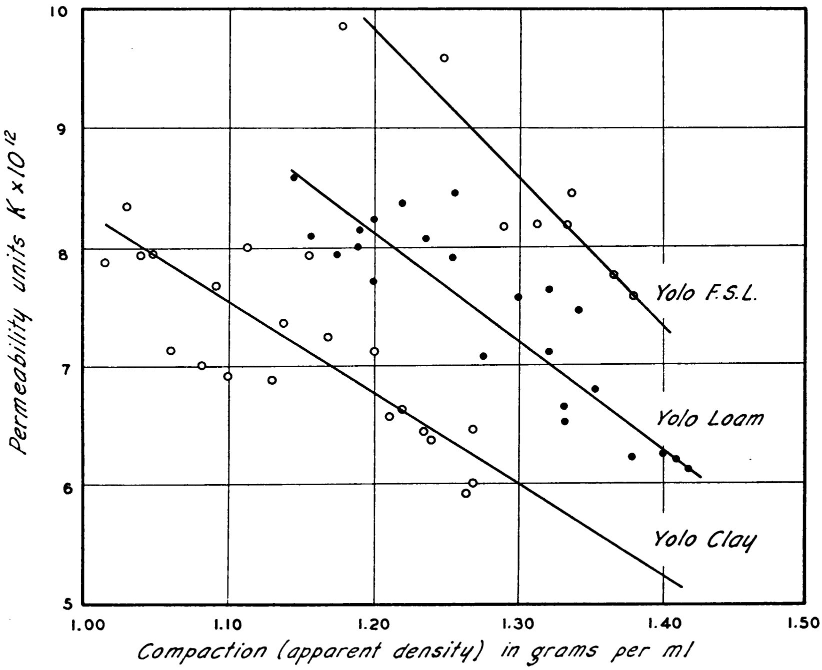

Fig. 1.—Effect of compaction (apparent density) on permeability of air-dry soils to carbon disulfide. Curves were drawn in by approximation; moisture contents of these samples were comparable with those reported in table 1.

of forces acting normal and parallel to the surface (shearing). Strictly speaking, both forces are acting simultaneously in all types of field compaction; but their relative magnitudes may vary greatly, thereby altering tremendously the permeabilities of field soils. Samples were prepared first in which the permeabilities of the soils were altered by varying the compression force applied. These are more or less simulated field conditions in which compaction has been produced by the application primarily of weight (such as heavy machines) on the top of the soil. In figure 1 the effect of compaction of the air-dry soil in this manner is shown by the curves that were approximated for three different textures. In all cases as the compaction (apparent density) was increased, the permeability was materially reduced.

The effects of compaction produced by compression and by shearing forces were tested on Dinuba sandy loam. One sample was compacted air-dry by a compressional method and its permeability measured. It was then moistened to near its moisture equivalent and its permeability determined again. A second sample was compacted while in the moist (approximate moisture equivalent) condition by working it with a spatula. Its permeability was determined. It was then dried to the air-dry condition and its permeability again measured. The results were as follows:

Dominant compaction force	Permeability when air-dry (about 2 per cent), $K \times 10^{12}$	Permeability when moist (about 12 per cent), $K \times 10^{12}$
Compression	7.50	1.70
Shearing	0.95	0.15

Both samples compacted by shearing had low permeability; in fact, the puddled sample was almost impermeable to the vapor.

Moisture.—Permeability measurements on soils were limited to samples in the air-dry condition and moistened to a water content of approximately the

TABLE 2

PERMEABILITY OF THREE TEXTURES OF YOLO SOIL TO CARBON DISULFIDE VAPOR AT TWO MOISTURE CONTENTS

Soil series and percentage moisture content	Permeability unit	Soil series and percentage moisture content	Permeability unit
	$K \times 10^{12}$		$K \times 10^{12}$
Yolo fine sandy loam:		Yolo loam (*Continued*):	
Low moisture content:		High moisture content:	
3.10	9.63	19.10	3.06
3.16	9.78	21.10	2.50
High moisture content:		22.60	0.64
15.60	2.25	22.40	0.67
17.70	0.66	23.50	0.33
18.10	1.50	Yolo clay:	
18.80	0.69	Low moisture content:	
19.90	0.23	5.75	7.12
Yolo loam:		6.10	6.24
Low moisture content:		6.10	6.37
3.05	7.43	High moisture content:	
3.75	8.00	31.30	0.67
3.75	8.20	31.40	0.90
4.20	7.73	32.30	0.31

moisture equivalent. Intermediate moisture contents of uniform distribution within the columns could not be obtained. Yolo soils of three different textures were used; data reported have been selected from many determinations on a compaction basis, only those of approximately 1.20 grams per ml being given. Results are presented in table 2.

At high moisture contents the permeabilities of all types are greatly reduced; in fact, some are almost impermeable. Yet about one fourth of the volume of each soil column is still occupied by gases. The nonsolid volume of the soil is apparently occupied by gases and water in approximately equal amounts.

Soil Series.—Several series of similar textures were compared. For a more complete picture of their permeabilities to carbon disulfide, soils at both low and high moisture contents are reported in table 3.

Permeability data are presented for Yolo, Salinas, and Hanford fine sandy loams, air-dry and moistened. The Hanford soil under the experimental conditions had a lower permeability than the Salinas and Yolo soils when dry; when wet Hanford has the highest value.

The Egbert, Yolo, Fresno, and Hanford loams are compared. Again the Hanford soil had the lowest permeability when dry, but the highest when moist, whereas the other series have values of about the same magnitude. When wet the Hanford is substantially more permeable than Egbert, Yolo, or Fresno soils of this texture.

Values for three clays are also given, indicating a lower permeability for the Stockton series than for the Salinas or Yolo clays.

TABLE 3

Permeability of Several California Soils* to Carbon Disulfide Vapor at Two Moisture Contents

Soil texture and series	Moisture content		Permeability units	
	Dry	Wet	Dry	Wet
	per cent	*per cent*	$K \times 10^{12}$	$K \times 10^{12}$
Fine sandy loam:				
Yolo	3.1	18.8	8.22	0.70
Salinas	3.1	16.9	8.42	1.89
Hanford	1.7	17.0	7.58	3.75
Loams:				
Egbert	7.7	32.2	7.90	2.25
Yolo	3.4	22.6	7.94	0.64
Fresno	3.2	15.9	8.43	2.18
Hanford	3.6	18.5	7.30	2.78
Clay:				
Salinas	8.9	30.5	6.95	1.51
Yolo	6.1	31.3	7.11	0.67
Stockton	7.1	27.1	5.60	0.60

* All soils were compacted at an apparent density of 1.20 grams per ml.

Temperature.—The effect of soil temperature on the movement of carbon disulfide vapor through the soil is discussed by Hagan[8]. In brief, as the temperature changes, the result is to change the partial pressure of the vapor, with the net result that for each 10-degree-C rise in temperature the movement of the vapor is increased by about 50 per cent.

DISCUSSION

Samples of surface soils of several types were obtained from widely separated locations in the Sacramento and San Joaquin valleys. Admittedly, preparing these soils for laboratory investigation has altered their natural condition by destroying their structural development to such an extent that the larger structural units no longer exist. This investigation involves both surface and subsoil, and the problem is concerned primarily with the soils under cultivation. The present method offers a satisfactory treatment of the surface soil. To gain further information on the permeability of subsoils, another technique has been developed, which will be discussed in a later paper.[9]

[8] Hagan, R. M. Movement of carbon disulfide vapor in soils. Hilgardia **14**(2):97–102. 1941.

[9] Hannesson, H. A., R. N. Raynor, and A. S. Crafts. Herbicidal use of carbon disulfide. (In press.)

According to the results of this investigation, the most important factors that may influence the movement of carbon disulfide are, first, the moisture content of the soil; second, the kind of compaction that produces a puddled condition; third, the temperature of the soil. One must consider all three factors collectively in understanding the movement of this gas within the soil under field conditions. To a lesser degree, soil texture may effect the movement. As the clay content increases, the permeability of the soil decreases in the samples prepared and studied under laboratory conditions. Since, however, the natural structure of the soil has been disturbed by the treatment, some allowance must be made when applying this conclusion to subsoil conditions unaltered by cultivation or to a soil profile in its natural state. A further conclusion is that no great difference in permeability of surface soil to carbon disulfide exists between the soil series studied except for minor differences, probably associated with moisture-holding capacities. One exception may be cited: of particular interest was the finding that permeability of the Hanford soils was highest of all the soils tested in the moist condition.

In the West, the formation of plow sole or plow pan after cultural practices is a serious problem. The data presented show that the permeability of the Dinuba sandy loam when puddled and wet approaches a zero value. They further indicate that even when the soil has been reduced to the air-dry condition the permeability value is very low.

The plow sole or plow pan occupies a critical position in the soil profile. Its ability to restrict the downward movement of carbon disulfide vapor toward the deep-lying roots is very significant.

Perhaps no single factor more affects the permeability of a laboratory-prepared soil to carbon disulfide than does moisture: as water is added to the soil, the effective conducting channels become smaller and smaller until, at a moisture content of approximately the moisture equivalent, the permeability value of the wet soil approaches zero. This fact would indicate that shortly after a soil has received an application of water by heavy rains or by irrigation, conditions for movement of carbon disulfide vapor in the tilled layer are extremely unfavorable. This suggests that injection of carbon disulfide should place the chemical beneath the tilled surface layer and that moisture content, even in the subsoil, should be low if free diffusion is to take place.

SUMMARY

Certain factors affecting the movement of carbon disulfide vapor in soils have been studied according to the method devised and reported by Hagan.

The permeability to carbon disulfide of several soil series and types from widely separated sections of the Sacramento and San Joaquin valleys in California was investigated by this method.

Under most conditions moisture is an important factor in influencing the movement of carbon disulfide vapor in soils. As the moisture content is increased, the permeability of the soil is decreased; a value of nearly zero is reached as the moisture content of the soil approaches its moisture equivalent.

Compaction, as in plow sole or plow pan, is very important in controlling the movement of carbon disulfide vapor under field conditions. If moist, such a layer may be almost impermeable to this vapor.

In cultivated surface soils, differences between textures are of less significance. The permeabilities of the lower-clay-content soils tend to be higher whether dry or wet. The effect of structure is not dealt with in this paper.

The full significance of differences in the permeability of individual soil series cannot be presented here, since only surface samples were studied in the granulated state. The results, however, indicate no great difference between soil series when in this condition; and information is being accumulated by other means on the permeability of the subsoils of several soil series in their natural condition.

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