Direct Measurement of Gaseous Diffusion in Soils

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Many factors have been suggested as contributing to the renewal of soil air. Among these are temperature variation, wind, barometric pressure changes, water movements, and diffusion. Undoubtedly all these factors do contribute, to some extent, to the exchange of soil air and atmospheric air, but it is generally believed that diffusion plays the predominant role.

Several studies (1, 5, 6, 7, 8, 9, 12, 13, 14, 15, 17, 22, 26, 27) have dealt with the movement of gases through soils. For the most part, these investigators have dealt with the characterization of soils on the basis of their air permeability, having measured the flow of the gas through soil under a pressure gradient. Most of the studies were carried out on artificially packed soil columns in the laboratory; some however, were carried out on soils in situ (12, 13, 15).

The factors affecting flow characteristics, such as porosity, nature of the pores, temperature and moisture content of the soil and of the gas, soil cover, freezing of the soil, pressure of the flowing gas, etc., were studied in a quantitative manner by the early German workers (1, 6, 8, 22, 26, 27). Much of this work apparently has been overlooked by recent investigators.

A knowledge of the laws governing the flow of gases in soils is of interest. Gaseous flow under a pressure differential, however, differs in several respects from the transfer of gases by diffusion. Buckingham (4) pointed out that gaseous flow varies as the sixth or seventh power of the porosity whereas the same author stated diffusion to vary with the second power. Other workers (10, 11, 21, 24) state that diffusion varies directly with porosity. Movement by diffusion differs from flow induced by pressure in that factors such as streamline flow, friction, and turbulence are absent where gases move by diffusion. Heinrich's work (12, 13) indicates that there may also be a rupture value for flow of gases through soils at low pressures and that the pressure required for flow reaches a maximum, and then decreases with increasing pressure to a certain minimum pressure. Romell (23) stated that when one seeks to use the permeability of a soil to air under applied pressure as a measure for its aeration, one does so on the hypothesis that mass flow plays the principal role and that diffusion is secondary. Since air permeability varies with the method by which it is determined and since it differs in its nature from diffusion, it is evident that these measurements are of limited value in making inferences regarding the diffusion mechanism in soils.

Hannen (11) was probably the first to study diffusion as such in soils. He used artificially packed soil columns about 10 inches long. Below the soil column he placed a chamber of carbon dioxide. After allowing diffusion to occur for a period of about 10 hours, he analyzed the remaining gas in the chamber. He concluded that the quantity of gas diffusing varied directly with the total pore space, or \( Q = kS \), where \( Q \) is the amount of gas that diffused through a soil having a pore space of \( S \), and \( k \) is a constant.

Buckingham on the other hand concluded from his data that the diffusion constant varied as the square of the pore space, or \( Q = kS^2 \).

Smith and Brown (24) attempted measurements of \( CO_2 \) diffusion in moist undisturbed soil samples in the laboratory. They stated that "accurate determination of the rate of diffusion could not be made" because of contamination from air passing through the soil column.

With samples of disturbed soil they found that the diffusion of carbon dioxide through air dry soil varied as a function of porosity of the soil within the limits studied. These limits were 36.4% to 64.5% porosity.

Two other studies have found a linear relation between porosity and diffusion. Both used artificially packed columns of varying porosity and both used the vapor of carbon disulfide as the diffusing gas. Hagan (10) concludes that the permeability of these artificially packed columns of varying porosity has been found to approach zero, not 100% porosity, but in a porosity range of 26 to 29%. Disturbed soil samples with moisture additions have a more uniform air-space porosity. Penman (21) carried out his work under very carefully controlled conditions in the laboratory. He used several air dry solids which, in addition to soils, included steel wool, mica, sand, and glass spheres. His results by the relationship, \( D/D_0 = 0.66S \), where \( D \) is the coefficient of diffusion through the material having a pore space \( S \), and \( D_0 \) is the diffusion coefficient through the apparatus used, is that, where \( S = 1 \), Penman's curve of diffusion vs porosity is a straight line with a slope of 0.66 up to a porosity of about 60%. Above this porosity, the slope was greater than 0.66.

The above mentioned experiments on gaseous diffusion were all carried out on soil samples whose natural structure had been greatly altered (Smith and Brown's attempt to study diffusion of natural structure samples failed). Samples were carefully taken in most cases to obtain uniform porosity in the sample. It is well-known that soils which show marked variation in uniformity on the basis of soil type and past history vary widely in porosity when samples are taken within a few feet of one another in the field. Furthermore, there is no uniformity in porosity within any given sample even when samples are carefully taken.

The purpose of this study was to examine the process as it occurs on undisturbed soils in situ under applied overall pressure differentials. It is believed that only way of fully understanding the process as it occurs under natural conditions is to carry out studies on soils where physical homogeneity does not exist. Relation between diffusion and porosity of different soils is shown.

Diffusion rates are shown on soils under different conditions of moisture in the absence of any other factor. Diffusion rates on soils with different tillage practices have been shown.

APPARATUS AND METHOD

Carbon disulfide, as used by Penman and Hagan, has several advantages in a study of gaseous diffusion, by virtue of its volatile nature. However, neither of the methods used by investigators was adaptable to use on soils in the field. The use of the vapor of liquid carbon disulfide was readily adopted in this study. A hole was bored into the soil to 1-foot depth with cylindrical tubing. The outer edge was tapered inward to prevent compression of the sides of the hole. A fine-pored clay cup was placed in the soil, and a known amount of carbon disulfide was then placed in the cup. The cups had the advantage of presenting a very small area over the outer surface of the cylinder. Carbon disulfide soaked through the pores of the cup and there was no diffusion from the cylinder into the soil air.