PROJECT OBJECTIVES

Field soil lysimeters and soil core samples were used in these research studies of soil oxygen:

a) To characterize diffusion and transfer of oxygen through the soil profile under static and dynamic moisture conditions.

b) To determine soil oxygen diffusivities as a function of soil water content.

c) To determine the oxygen status of soil water and soil air in the soil profile with regard to oxygen consumption within the soil profile.

ACHIEVEMENT OF PROJECT OBJECTIVES

The degree to which the objectives were achieved in this project is given in detail in the Masters thesis cited in the reference section. In general:

a) A solution of Fick's second law of diffusion

\[ \frac{C}{C_0} = 1 - \frac{4}{\pi} \sum_{n=1}^{\infty} \left( \frac{1}{2n-1} \right) \sin (px) \exp (-p^2D't) \]

described the non-steady state diffusion of oxygen in soil core samples over a wide range of soil air-space porosities obtained by varying the soil moisture content. However, the initial and boundary conditions associated with the mathematical model must be considered when determining soil oxygen diffusivity \( D' \) from experimental data. In particular, short time measurements were shown to cause errors of about +20% in \( D' \).

b) In a soil of given total porosity soil oxygen diffusivity was
functionally related to volumetric moisture content as shown by others in artificially packed soil but in undisturbed soil the values of diffusivity were found to be an order of magnitude lower at similar soil air-space porosities. Within the soil profile, soil layers were characterized by distinct diffusivity-porosity relationships such that single diffusivity value could be not assigned to the entire profile.

c) The oxygen status of soil air and soil water could be determined at various depths within the soil profile based on oxygen consumption (activity) within the profile and diffusivity (from laboratory measurements). Values of oxygen consumption in soil at given temperatures could be determined by field measurements of water, bulk density and temperature and using the steady state equation:

\[
C(x) = C_0 + \frac{a}{2D'} (x-2L)
\]

after correcting D' for temperature (where a = activity, x = soil depth, and c = oxygen concentration).

RESEARCH PROCEDURES USED

Soil oxygen diffusivities were determined by the transient method of Papendick and Runkles modified for use with undisturbed soil core samples. Continuous recording of oxygen concentration with time was employed using polarographic type oxygen probes. Moisture equilibration in soil cores was accomplished by pressure plate methods described by Richards. Soil core samples were taken with a sampler developed by Tanner. Soil bulk density was determined by wax-sealing the core and subsequent immersion in water to determine loss in weight through buoyancy.

Field measurements included use of the oxygen probes, thermocouples, and a data acquisition system (Digitek) for sequential sampling and record print-out. Soil moisture was measured by the neutron scattering technique (Nuclear-Chicago neutron moisture probe).

Computation and data reduction was accomplished using the IBM 360 computer at the University of Connecticut Computer Center.

Four field lysimeters were used consisting of 76 cm diameter clay tiles filled to a depth of 100 cm with Enfield fine sandy loam soil. Bluegrass sod was developed on the soil one year prior to sampling. Soil oxygen diffusion chambers were placed at various depths in each lysimeter into which were inserted the oxygen probes. Probe currents were recorded sequentially over time. Probe current is proportional to the rate of oxygen reduction at the probe surface which is a function of oxygen concentration in the diffusion chamber. The amount of oxygen reduced per unit time has a negligible affect on the oxygen concentration in the diffusion chamber.
A technique was developed for sealing the soil core samples in heat shrinkable plastic sheeting and urethane plastic to obviate diffusion along the sides of the cores during diffusivity determinations and to prevent loss of soil during handling of the soil cores.

RESULTS OR CONCLUSIONS

Three main conclusions may be drawn from these studies on soil oxygen movement through the soil profile.

1. A solution of Fick's law of diffusion (presented under achievement of objectives section) described the non-steady state diffusion of oxygen through various soil layers over a wide range of air-space porosities in soil.

   In a practical sense, the ability to determine soil oxygen diffusivity, as in this study, allows characterization of soil aeration properties of the soil profile for use in biological studies of oxygen demand in the soil. Of greater significance in this research it was found that soil oxygen diffusivity values were much lower than those reported in the literature by an order of magnitude. It appears that the reason for this lies in the fact that the literature values are based on a) non-soil materials and b) artificially packed soil columns using sieved soil materials. The latter does not represent true soil conditions in that a portion of the finer soil particles was excluded from the study. Evidently these fines have a significant affect on diffusivity.

2. The relationship between soil oxygen diffusivity and air-space porosity was found to be curvilinear and of the form

\[
\frac{D'}{D_0} = \Phi E^n
\]

as reported by others for dry or low moisture content materials. Our data show the relationship to hold for high moisture levels as well. This fact allows comparison of diffusivities of different soil layers in the profile by regression analysis. Studies on field lysimeters using this method showed significantly different soil layers present within the profile with regard to diffusion of oxygen. Thus (unfortunately in an applied sense) no single function of soil oxygen diffusivity-soil porosity relationship may be assumed within a given soil profile. However, recognition of this may lead to differentiation of soils on the basis of "oxygen supplying power" where this consideration is important (e.g. in utilization of soils for aerobic waste disposal sites). Soils with large diffusivity values throughout the profile will have a faster oxygen transfer to greater depths within the profile thus tending to maintain aerobic conditions at these depths.
3. Quantitative determination of oxygen consumption rates (activities) at various soil depths was shown possible using diffusivity values determined in the laboratory on soil cores plus field measurements of soil water content, bulk density, temperature, and oxygen concentration profiles. The steady state equation for oxygen concentrations in the soil profile

\[ C(x) = C_0 + \frac{\alpha x}{2D}, \quad (x-2L) \]

was used to determine activities (a). The limiting value of \( C(x) = 0 \) could be used in this equation to determine the maximum activity value hypothetically possible at a given soil depth within the limitations previously mentioned for distinct soil layers. Good agreement was obtained between published and measured activity values and those determined in the field through the use of this equation.

LIST OF PUBLICATIONS


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ABSTRACT

Studies of soil oxygen diffusion into and through the soil profile were conducted to determine the oxygen status of soil under varying soil moisture conditions. It was found that soil oxygen diffusivity was related to soil air-space porosity even at high soil moisture levels such that the relationship could be described by a single function. In this manner different soil layers within the profile were found to have distinct diffusivity-porosity relationships. Significantly, soil oxygen diffusivities were found to be an order of magnitude lower than published values for disturbed soil samples showing that it is necessary to determine diffusivity on undisturbed soil core samples if field conditions of soil oxygen transfer systems are to be studied.

Field lysimeter studies indicated that oxygen consumption at different soil depths could be calculated from diffusivity measurements and field measurements of soil moisture, bulk density, temperature, and oxygen concentrations. Too, in a similar manner, maximum activity (oxygen consumption) could be predicted for a given soil and soil depth thus enabling classification of soils as to their oxygen supplying potential.
KEYWORDS

soil oxygen
oxygen diffusivity
soil activity
diffusion
porosity-diffusivity
soil lysimeters
soil moisture
soil aeration