REPRINTED FROM NETHERLANDS JOURNAL OF AGRICULTURAL SCIENCE
VOL. 8 No 4 NOVEMBER 1960

SOME EXPERIENCES IN SOIL AERATION MEASUREMENTS AND RELATIONSHIPS TO DEPTH OF ROOTING[1])

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SUMMARY

A description is given of an apparatus for measuring availability of oxygen in the soil, built according to the principle published by LEMON and ERICKSON. Adaptations in construction of the electrodes to adapt them to rugged work are described.

Examples of the performance of the instrument are given, derived from measurements taken where aeration of the soil had also been recorded by visual inspection. As a rule a good correlation between measurement of O_2-diffusion rate and soil characteristics and root penetration pertained.

The explanation of some at first sight abnormal results is given.

1 INTRODUCTION

As shallow rooting may result in decreased growth of a crop and smaller yield, it is most important to be able to determine what exactly is the main factor governing limited downward growth of the roots. The two most important factors are mechanical resistance and lack of oxygen, which is usually the result of a surplus of water. Both factors are closely linked under many circumstances, so that the study of the soil profile does not allow us to conclude on the nature of the main causative factor.

Since LEMON and ERICKSON (1) published a method of measuring oxygen diffusion rates in the soil by means of a platinum micro-electrode a separate appraisal can be made of the aeration factor in dense soil layers. As the obtained values are also closely correlated with soil structure (2, 3, 4) and moisture content (5, 6) it seemed worthwhile to obtain field experience with this method, with the ultimate purpose to establish critical oxygen diffusion rate values for the roots of different crops.

The attractiveness of this method of measuring aeration lies in the fact that the conditions at the Pt-electrode closely resemble that of the root in the soil. Both are thin cylindrical units consuming oxygen and dependent on supply of oxygen as regulated by diffusion in the soil air phase and by diffusion resistance through the water film covering both their surfaces. A second point in favor of the method is its simplicity and the speed with which single readings can be obtained.

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[1]) Received for publication August 5, 1960.

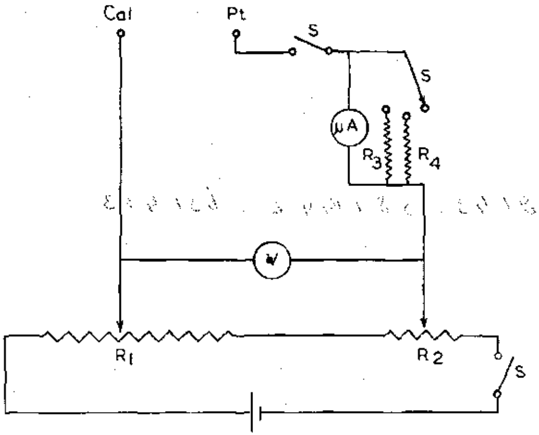

FIG. 1 DIAGRAM OF THE ELECTRIC CIRCUIT OF THE OXYGEN DIFFUSION METER.
Cal, Pt = electrodes
R_1, R_2 = potentiometers
R_3, R_4 = shunt resistance
S = switch
V = Voltmeter
A = micro-ammeter

2 DESCRIPTION OF THE APPARATUS

The apparatus was built according to the principle as published by LEMON and ERICKSON (1). In the details of the electric circuit the construction as used by POEL (7) was followed. Fig. 1 gives a diagram of the electric circuit.

As in many cases the measurements had to be made at greater depth in the soil the more simple electrodes, with a short piece of Pt-wire protruding at the tip, were not rugged enough. So a more sturdy type of tip was devised, which was mounted on the end of a thick-walled metal tube. The construction details are given in fig. 2.

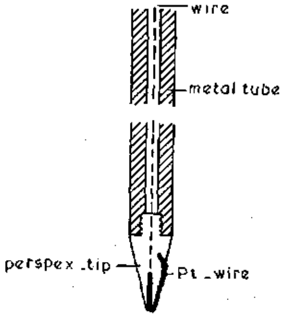

FIG. 2 CONSTRUCTION DETAILS OF A RUGGED Pt-ELECTRODE.

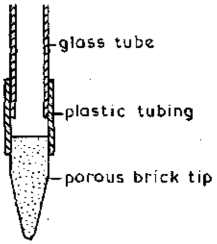

FIG. 3 TIP OF THE CALOMEL ELECTRODE.

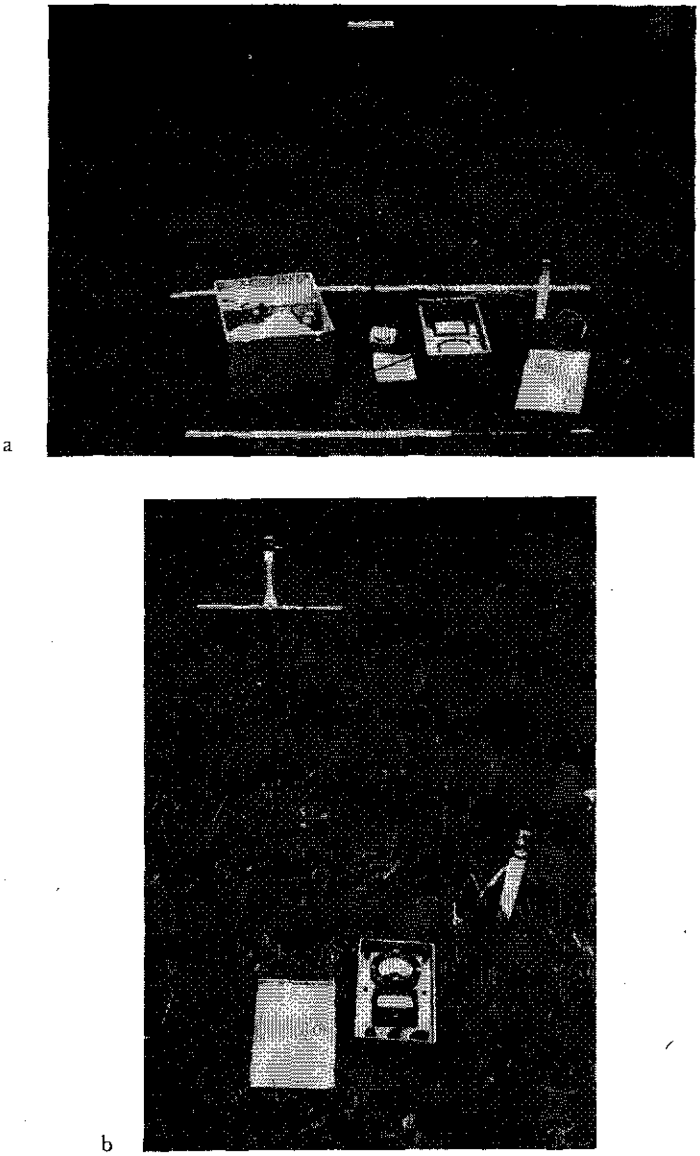

Fig. 4a Complete apparatus, with a second Pt-electrode in a shielding plastic tube and accessory kit.
b Box containing electric circuit and both electrodes during measurement.

To achieve a large contact area with the soil, without loss of much of the saturated KCl-solution, also a special tip for the calomel-electrode was made. It consists of a somewhat conical piece of soft fine brick, taken from the wall of a piece of drain-pipe (fig. 3).

All in all the whole set-up for measurements in the field is contained in two small wooden boxes along with the longer metal electrodes, covered with a piece of plastic tubing to avoid damage of the tips during transport. The complete apparatus in use, with accessory kit, is shown in fig. 4.

3 PERFORMANCE OF THE APPARATUS

A number of other workers have already given examples of the performance of their instruments.

One of the main features of the instrument when taking a reading is the slow decrease in current flowing through the micro-ammeter as the direct stock of oxygen around the Pt-tip is depleted and the equilibrium status governed by oxygen diffusion toward it is attained. If the aeration in the soil is low, equilibrium is attained faster than when more oxygen is present. The graphs in fig. 5 clearly depict the course of readings with one minute intervals over five minutes at different soil depths with a clear decline in aeration. The same can be noticed in table 1, where the gradual decrease of oxygen diffusion rate in a clay soil under pasture has been measured to the ground water level.

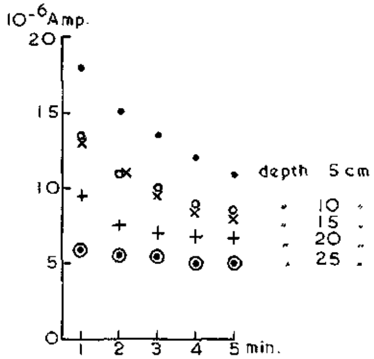

FIG. 5 TIME-COURSE OF CURRENT DURING 5 MINUTES AT DIFFERENT DEPTHS IN A CLAY SOIL.

In most publications, where this method has been used, the micro-ammeter readings have been converted to oxygen diffusion rates in g $O_2/cm^2/min$. To be able to do this the exact surface of the platinum wire exposed to the soil has to be known. In our case the estimation of the surface of the bent Pt-wire is more or less impossible. So all data have been recorded in micro-ammeter readings. The drawback is that only measurements taken with the same electrode are completely comparable. But usually the relative values are quite sufficient and in many cases they can be related to the readings obtained in anaerobic soil.

As the graphs in fig. 5 indicate it takes some time before real equilibrium

Table 1 Decrease of oxygen availability with increasing depth in a heavy clay soil.

Depth in cm	Micro-ammeter readings after		
	1 min.	2 min.	3 min.
10	36	32	31
20	31	28	27
30	24	22	21
40	23	22	21
50	23	21	20
60	22	18	16
70	14	11	10

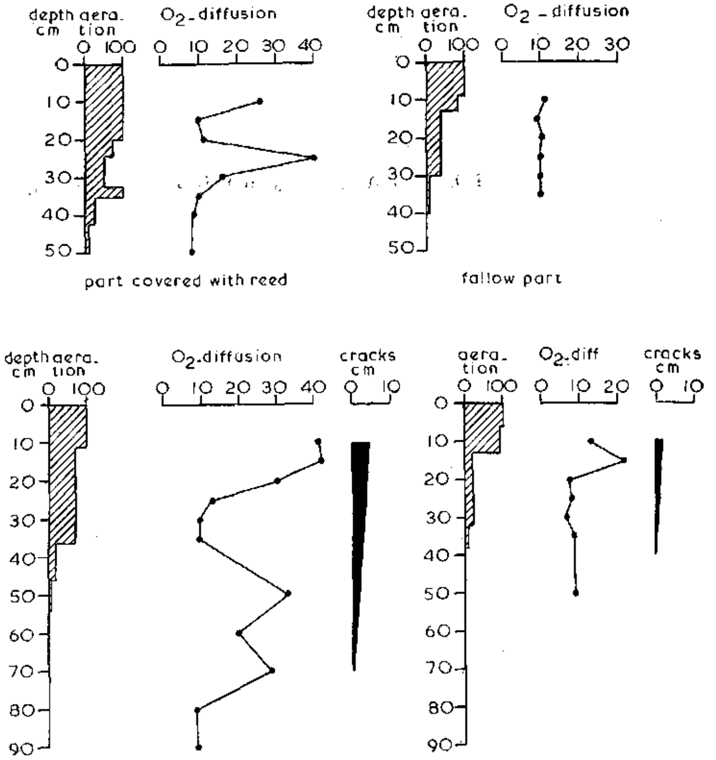

Fig. 6 Comparisons of soil aeration on adjacent reed-covered and fallow plots in the Oost-Flevoland polder. The main mass of reed-rhizomes is located at about 15–20 and 30 cm depth. Increased O_2-availability to greater depths in the soil as a result of water extraction by the heavy Phragmites vegetation.

is attained. In carrying out determinations in the field readings were always taken after three minutes.

The data in table 1 and fig. 5 give a good demonstration of the gradual decline in aeration going downwards in a fairly homogeneous profile in clay soil. This is what should be expected.

In a number of cases it was possible to compare readings obtained with this instrument with aeration data obtained by visual estimation of the soil color along the side of pits dug for studying the soil profile and rooting depth. In fig. 6 four series of estimations which have been carried out on experimental plots in the newly reclaimed Oost-Flevoland polder are given. Twice a comparison has been made between fallow soil and a reed (Phragmites communis Trin.) covered plot as regards the "ripening" and dessiccation of the newly exposed clay soil. It is clearly evident that under the heavy reed vegetation much water has been taken out of the soil, resulting in formation of heavy cracks and a far better penetration of oxygen into the deeper layers. As the observations on the profile, which had been carried out by workers of the institute in Kampen were taken about two months earlier in the summer it is not surprising that the O_2-diffusion measurements show an increased aeration at greater depths. Why the O_2-readings are so very low

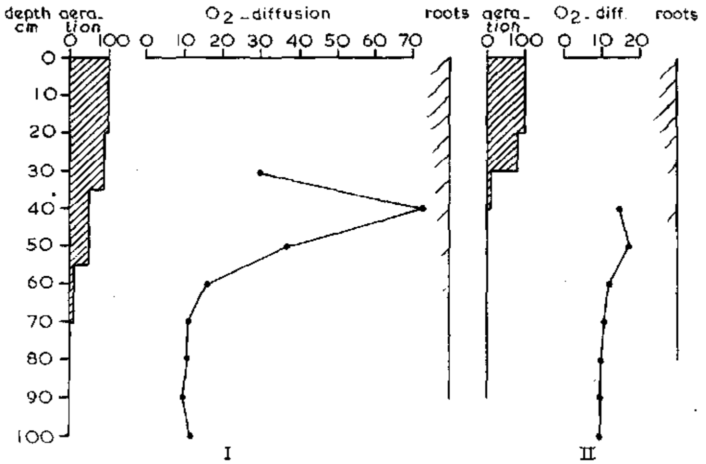

FIG. 7 COMPARISON OF A FERTILIZED (I) AND AN UNFERTILIZED (II) PART OF A FIELD AS REGARDS SOIL AERATION.
I THE HEAVIER CROP HAS BROUGHT ABOUT GREATER DESSICATION OF THE SOIL AND PENETRATION OF AIR TO GREATER DEPTHS.

in the soil layer, where the main mass of rhizomes of the reed is located, is not understood.

In fig. 7 an example is given of readings obtained in an already cultivated part of the same polder. A comparison has been made of the soil in two adjacent plots, which had carried their first crop. Part of the crop had been well fertilized and part received no fertilizer. Fertilization had resulted in a heavier crop and consequently increased loss of transpired water. The result has been deeper rooting and enhanced penetration of air into the deeper soil layers. Again there is a good correlation between the measurements and the data obtained on visual inspection in the pits.

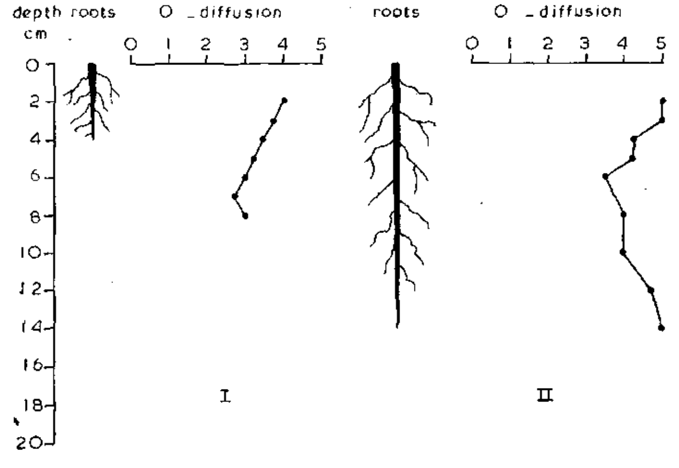

FIG. 8 AVAILABILITY OF OXYGEN AND ROOTING DEPTH
I WATERTABLE JUST UNDER SOIL SURFACE
II WATERTABLE ± 16 CM BELOW SOIL SURFACE.
READINGS TAKEN WITH A Pt-ELECTRODE WITH A MUCH SMALLER SURFACE.

An attempt to obtain data on a more detailed correlation between oxyg availability and depth of root penetration was made on an experimental field, where the influence of different levels of water-table on the growth of colza was being studied. The field was again located in the Oost-Flevoland polder and the experiment conducted by the institute in Kampen. In fig. 8 the results and observations are depicted. Both availability of oxygen and depth of rooting are less on places where the watertable was very high. The results suggest that no roots will grow in soil when the O_2-diffusion rate is so low as to give micro-ammeter readings of 3 or less when using a certain small Pt-electrode.

In a number of cases some at first sight erroneous readings were obtained. It may happen that the values recorded in the uppermost layers of soil – examples in fig. 6 and 7 – are lower than somewhat deeper. This only occurs when the topsoil is dry. The explanation is that under these circumstances there is insufficient moisture in the soil to wet the complete electrode surface, so that the electrode is partially inactivated.

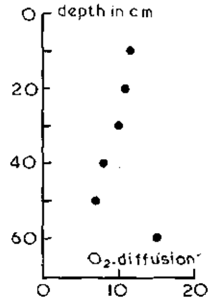

FIG. 9 OXYGEN DIFFUSION RATES IN A SOIL, WHERE A THICK LAYER OF CLAY OVERLIES A COARSE SAND SUBSOIL.

In fig. 9 a result is depicted, which also shows an unexpected trend. First there is a gradual decrease in availability of oxygen with increasing depth, but at 60 cm a much higher reading is recorded. This kind of result, which has been obtained a number of times, was encountered on soils where a layer of clay soil was overlying a deeper deposit of rather coarse sand, dense and still above ground-water table. It seems logical to assume that the much better mobility of the gaseous oxygen in the macropores devoid of water is responsible for this effect.

As it seems that quite often roots hardly penetrate into these sand layers, which may be very compact and rigid, it may be concluded that in such cases mechanical impedance is the sole factor governing root penetration.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the willingness with which soil data collected by workers of the Agricultural Department of the "Directie van de Wieringermeer, Dienst Noordoostpolderwerken – Oostelijk Flevoland" were put at his disposal.

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