THE EFFECT OF OXYGEN SUPPLY ON THE GROWTH AND THE INCIDENCE OF ROOT-ROT IN BEANS.

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The Effect of Oxygen Supply on the Growth and the Incidence of Root-Rot in Beans.

by

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ABSTRACT

The Effect of Oxygen Supply on the Growth and the Incidence of Root-Rot in Beans.

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A greenhouse experiment was conducted on Sims clay loam and Breckenridge sandy loam in an attempt to determine the relationship of oxygen supply to the incidence of root-rot in beans (Phaseolus vulgaris var. Sanilac). The oxygen status of both soils was determined by the platinum micro-electrode method of determining oxygen diffusion rates. There were four treatments and six replications for each soil. Circular pots, nine inches in diameter, were cut into various lengths; the difference in heights of the soil columns above a free water surface established differences in the oxygen diffusion rates of the soils contained.

In the first trial the pots were wetted with moisture but only 7.6 percent of all the seeds planted, germinated. The soils were discarded, then replaced and the seeds were planted under drier conditions so

that germination approximated 100 percent.

The differences in vegetative growth, root-shoot ratios and root-rot indices were associated with the amount of oxygen available to the plants. Vegetative growth was in accordance with the amount of soil contained in the pots, and the root-shoot ratios increased with increasing oxygen diffusion rates. The root-rot indices showed that the most severe cases were associated with the lowest oxygen diffusion rates. This was true for both soil types. However, the root-rot cases were more severe on plants growing in the clay loam soil.

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INTRODUCTION

Respiration is a vital process of living plant roots. The rate of oxygen diffusion to the surface of these roots rather than the absolute amount or concentration of this gas in the soil, is important in plant growth. Normally the direction of oxygen diffusion is down a concentration gradient from the supply of oxygen in the atmosphere to the soil pores, through water films surrounding the roots, and to the roots.

Low oxygen supply causes the development of anaerobic respiration and is associated with the activity of certain plant diseases. Absorbtion and nutrient uptake by roots requires energy which is supplied by the oxygen dependent, the lack of which greatly impairs growth.

The objectives of this research were:-

(a) to grow beans under different oxygen diffusion rates;

(b) to correlate the growth obtained with the incidence and intensity of root-rot.

LITERATURE REVIEW

Direct evidence of the necessity of oxygen for the proper functioning of roots was obtained by a number of early investigators who showed that the respirational behaviour of roots, tubers and other underground parts was significantly curtailed or stopped by the absence of oxygen from the medium.

Anike (1901) experimented with lupines and concluded that the lupine roots grew more rapidly in soil and water cultures when streams of air were passed through the culture media. Knight (1924), Free (1936) and Allison and Shive (1941) stressed the importance of ample oxygen supply to the roots and showed that different species growing under the same conditions vary in their oxygen requirements.

Bertrand and Peterson (1950) discovered that root branching, length, area of root surface and the number of root hairs are all increased by proper oxygen supply. Loehwing and Knight (1924) emphasized the fact that under low oxygen supply there is reduction in magnitude and rate of absorbtion of nutrients resulting in less developed foliage. Rich and Hunter (1925) and Steward and Street (1947) have shown that the aeration of nutrient cultures results in highly significant increases in plant growth of a large number of species.

Miller (1938) and Meyer and Anderson (1939) reported that the germination of seeds of many plant species was strongly affected by the concentration of oxygen and carbon dioxide in the medium. Bibbey (1948) experimenting on weed seed germination, stated that seeds of many common weeds may be buried in the soil for years without germinating, but when the soil is plowed or disturbed so that these seeds are brought near the surface germination usually occurs promptly as a result of adequate oxygen supply.

Boynton and Reutner (1939) substantiated the work of Cannon (1925), and later Compton (1947) and Seeley (1948) found similar results from experiments on the effect of relatively low oxygen concentration on the growth of roots. They showed that there exist critical oxygen concentrations for different phases of root activity. Ulrich (1942) found that the organic acid content of excised barley roots decreased approximately 27 percent when they were subjected to zero oxygen treatment for eight hours. At oxygen levels of 3.2 percent and higher the organic acid content was independent of the oxygen treatment.

Oskamp, Bradfield and Batjer (1934) proved that variation in supply of oxygen to the soil brings about characteristic changes in chemical and biological reactions. In the absence of adequate amount of oxygen anaerobic respiration predominates with the formation of large amounts of reduced soil constituents. Lawton (1945) found that

the order of reduction in nutrient absorbtion by corn from Clyde silt loam as a consequence of restricted oxygen was K > Ca > Mg > N > P.

Erickson (1946) found that tomato plants growing in an aerated medium showed increase in growth and water uptake over those growing in a non-aerated medium. Hoffer (1945) and Henderson (1934) working with corn suggested an inter-relationship between water uptake and oxygen supply. They concluded that more water was taken in when oxygen was adequate.

Buckingham (1904) was the first to give definite information as to the rate of gaseous movement in soils. He showed that air movement was by mass and diffusion flow but the latter was more predominant. Taylor (1949) developed methods of measuring oxygen diffusion rates in the soil. His success enabled Raney (1949) to successfully make field measurements of gaseous diffusion in the soil with an oxygen-deficient absorber. Russel (1950) believed that the evaluation of conditions at the interface between the root surface and the soil system presents the greatest possibility of ascertaining the influence of soil aeration on plant growth. As the active root surfaces are covered with water films, this interface is the cell-wall liquid-phase boundary of the root and water film. Movement of oxygen from the atmosphere to the actively respiring cells of the plant roots involves not only diffusion through the gaseous phase of the soil, but also through the gas liquid-phase boundary and the liquid phase of the water film.

Lemon and Erickson (1952) demonstrated that the current obtained in the electrolysis of an electro-reducible material as oxygen, at the surface of a platinum electrode can be used to calculate the rate of oxygen diffusion of that material to the surface. Measurements made in the soil based upon this principle provide a new, simple, rapid and inexpensive method of determining the rate of oxygen supply to an undisturbed environment similar to that in the liquid film surrounding the actively respiring plant root.

Archibald (1952) using the technique of Lemon and Erickson, measured the effect of limited oxygen on the growth of sugar beets and oats as successive crops on the same soil. Wiersma and Mortland (1953) experimenting on sugar beets, found that the length and shape of the beets were related to oxygen diffusion rates. Van Doren (1955) working with sugar beets, used the platinum micro-electrode method of Lemon and Erickson. He showed that emergence of beet seeds was influenced by oxygen diffusion rates. The emergence data suggested that there is a limit of oxygen availability below which plants will not germinate, or if they germinate they will not emerge. This threshold seems to be different for various crops and even different varieties of a particular crop. Transplanted crops die or exist unthriftily at or below the oxygen-rate-threshold value for that plant.

Cline and Erickson (1959) grew Green Seeded Perfection garden peas under six different oxygen diffusion rates. These were obtained by varying the length of 8-inch diameter soil columns above a free water-table. The result showed that growth, yield and nutrient uptake by the peas were increased by increasing the oxygen diffusion rates.

EXPERIMENTAL PROCEDURES

The soils used in the experiments were Sims clay loam and Breckenridge sandy loam. Two cylindrical tin pipes 24 inches deep and 9 inches in diameter were constructed from stove-pipe. They were filled with soil to a height within one inch from the top. Each of the soils was supplied with moisture from the surface until the moisture penetrating appeared in the bottom of the pots. An inch of water was kept in the trays placed at the base. The oxygen diffusion was determined by the platinum micro-electrode method of Lemon and Erickson (18). The readings were recorded in micro-amperes and converted to grams of oxygen per square centimeter of electrode area per minute. Data from the tall cylinders were used to select the heights of soil columns to be used in the investigation. The heights selected were 5, 7, 10, and 15 inches for the clay loam with corresponding oxygen diffusion rates of 5×10^{-8} g.cm.$^{-2}$min.$^{-1}$, 14×10^{-8} g.cm.$^{-2}$min.$^{-1}$, 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$; and for the sandy loam 5, 6, 8 and 10 inches with corresponding oxygen diffusion rates of 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$, 40×10^{-8}g.cm.$^{-2}$min.$^{-1}$, 53×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 62×10^{-8}g.cm.$^{-2}$min.$^{-1}$. There were six replications of each treatment.

The pots were placed in circular trays one inch deep, and were filled with soils to within one inch of the surface. They were then wetted with moisture. Three experiments were completed. Twelve bean seeds (Phaseolus vulgaris var. Sanilac) were planted one and one-half inches deep in each pot (Experiment 1). After planting, the soil surface was kept moist by an occasional wetting. Due to the very low oxygen diffusion rate, very few of the seeds germinated and six days later the top six inches of soil from all the pots were removed and replaced from the stock supply of the two soils. Twelve seeds were again planted in each pot and sufficient moisture supplied so that good germination would result (Experiment 2).

After this experiment was completed the soils were discarded and the pots refilled with a new supply of the soils so as to eliminate any root-rot organism present. The pots received the same quantity of soil as was used in the previous experiment and were filled to within one inch of the surface. Twelve seeds were planted as before in each pot but with carefully adjusted moisture content. The inch of moisture at the base of each pot was not supplied until a week after germination (Experiment 3).

The weights of the roots and shoots were obtained and the root-shoot ratios calculated for the plants grown under Experiments 2 and 3. The root-rot indices were determined by setting up six index classes which were:-

0 - no infection;

1 - small local lesions;

2 - lesions coalescing on the hypocotyl;

3 - lesions extensive on the hypocotyl or roots or on both;

4 - lesions severe on the hypocotyl and root system (root system non-functional);

5 - roots dead or nearly so.

An analysis of variance of the data was made.

EXPERIMENT 1

Twelve bean seeds (*Phaseolus vulgaris* var. Sanilac) were planted one and one-half inches deep in each pot. After planting, the soil surface was kept moist by occasional light wetting.

Results and Discussion

Four days after planting, ten seedlings had emerged from four pots containing the clay loam which had an oxygen diffusion rate of 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$, and four seedlings emerged from three pots containing the sandy loam soil which had an oxygen diffusion rate of 62×10^{-8}g.cm.$^{-2}$min.$^{-1}$. A day later, two more seedlings emerged in the clay loam soil and four in the sandy loam. Those that emerged at this time were not as healthy as the previously emerged ones and the cotyledons showed signs of decay. Those were the only seedlings which germinated, and the soils were then examined and the remaining bean seeds which were planted were found to be decayed.

The extremely low oxygen diffusion rate had contributed to the small percentage of germinated seeds and the subsequent decay of the others. As a result of this extremely low oxygen diffusion rate in the soils it was not possible to continue the experiment. Other experiments were designed to supply oxygen -- from adequate diffusion rates to diffusion at more critical rates, as shown in Table I.

TABLE I

Oxygen Diffusion Rates in Pots of different heights containing Sims clay loam and Breckenridge sandy loam.

Sims Clay Loam

Depth of Soil Column in inches	Oxygen Diffusion Rates gm. x 10^{-8} cm.$^{-2}$ min.$^{-1}$
5	5
7	14
10	31
15	50

Breckenridge Sandy Loam

Depth of Soil Column in inches	Oxygen Diffusion Rates gm. x 10^{-8} cm.$^{-2}$ min.$^{-1}$
5	14
6	40
8	53
10	62

EXPERIMENT 2

Twelve seeds were again planted in each pot and sufficient moisture supplied so that good germination would result. Within four days germination was approximately 100 percent. For the first ten days after germination, the plants received small but regular supplies of water at which time they were watered heavily and the inch of water was maintained at the base of each pot. The pots were examined twice daily and the water content regulated to the one-inch depth.

Results and Discussion

About five days later physiological conditions began showing up in the yellowing of many of the basal leaves of beans growing in the pots six and seven inches deep. Yellowing was more pronounced in the plants growing in sandy loam than in those growing in the clay loam. This developed rapidly and within a week from the time the first symptoms appeared more than 50 percent of the leaves of the plants growing in the soils with very low oxygen diffusion rates had developed different degrees of yellowing. The plants in the soil with oxygen diffusion rate of 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ showed very little effect and those in soil with rates above 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$ had not yet been affected.

Figure 1 shows plants that were grown in three pots of clay loam soil with oxygen diffusion rates of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$, 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$. The plants not only differed in size but also in physiological appearance, that is, the degree of yellowing. Those in soil with oxygen diffusion rate of 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ were twice as tall as those where the oxygen diffusion rates were 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$. Plants in soil with 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$ oxygen diffusion rate were three times as tall as those where the oxygen diffusion rates were the lowest. The beans growing in pots with diffusion rate of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$ showed a concentration of roots on the surface of the soil. The number of roots on the surface was reduced as the oxygen diffusion rates increased and was absent in the pots with the highest rates of oxygen diffusion. This was due to the presence of adequate oxygen for root respiration at the surface of the soil that was lacking within the soil itself.

A shift from the vegetative to the reproductive phase may occur whenever environmental conditions become such that the requisite internal conditions leading to flower induction are established. Under certain environmental conditions a plant may remain in the vegetative state or may initiate flowering earlier than usual. Flower initiation was first observed in plants growing in soil where the oxygen diffusion rates were

$14 \times 10^{-8} g.cm.^{-2} min.^{-1}$ or less. Apparently these plants matured earlier due to undesirable physiological conditions. Although there was earlier initiation of flowers, fruit-setting was of a long duration. When the fruits had eventually been formed they were few per plant, bearing a maximum of two seeds per pod. Most likely these would never develop into normal, healthy grains since the plants were highly chlorotic or devoid of leaves for food manufacture.

Figure 1. Plants that were grown in three pots of the clay loam soil at different oxygen diffusion rates are shown above. The pot to the left, with plants showing stunted growth and a severe degree of yellowing, had an oxygen diffusion rate of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$, the pot in the center had a rate of 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$, and the pot to the right, with plants showing vigorous growth, had a rate of 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$.

ROOT-SHOOT RATIO

There was considerable variation among the root-shoot ratios for the plants growing in the various pots. The highest root-shoot ratio was found in the clay loam having an oxygen diffusion rate of 50×10^{-8}g.cm.$^{-2}$min.$^{-1}$. This average was 1 to 12. The corresponding lowest ratio was obtained from plants with oxygen diffusion rate of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$, and this average was 1 to 3.4. The root-shoot ratios for plants growing under other oxygen diffusion rates were within these two extremes. Undoubtedly soil conditions were more favourable for better vegetative growth of plants with higher rates of oxygen diffusion than those with lower rates. The root-shoot ratios for plants growing under lower oxygen diffusion rates varied from 1 to 2 to 1 to 5 for the sandy loam, and from 1 to 2.8 to 1 to 5 for the clay loam.

The root-shoot ratio was affected by the soil water content, In general, a relatively low soil water content provided high rates of oxygen diffusion which favoured relatively high root-shoot ratios, while the opposite conditions were accompanied by plants with low root-shoot ratios.

The root-shoot ratios which are given in Table II are computed on a fresh weight basis, but undoubtedly would show essentially the same ratios if expressed on a dry weight basis. The results indicate clearly that the root-shoot ratio decreased with increasing moisture and decreasing oxygen diffusion rates. The data provide evidence that the variation in weight of the roots, shoots and root-shoot ratio was the effect of oxygen diffusion rates. Plants that were grown in sandy loam with an oxygen diffusion rate of 14×10^{-8} $g.cm.^{-2}min.^{-1}$ showed no significant difference in the weight of the shoots when compared with those grown in soil with an oxygen diffusion rate of 40×10^{-8} $g.cm.^{-2}min.^{-1}$. There was a significant difference, however, at the five percent level between those grown in soil with an oxygen diffusion rate of 14×10^{-8} $g.cm.^{-2}min.^{-1}$ and those with a rate of 53×10^{-8} $g.cm.^{-2}min.^{-1}$, also between those in soils with diffusion rates of 53×10^{-8} $g.cm.^{-2}min.^{-1}$ and 62×10^{-8} $g.cm.^{-2}min.^{-1}$. A significant difference was obtained at the one percent level between plants where the oxygen diffusion rates were the two extremes.

Similar results were obtained for plants grown in the clay loam. There was no significant difference between plants grown in soils with oxygen diffusion rates of 5×10^{-8} $g.cm.^{-2}min.^{-1}$ and 14×10^{-8} $g.cm.^{-2}min.^{-1}$. There was a significant difference (five percent level) between shoot weights where the oxygen diffusion rates varied between 5×10^{-8} $g.cm.^{-2}min.^{-1}$ and 31×10^{-8} $g.cm.^{-2}min.^{-1}$, and similarly between rates of 31×10^{-8} g.cm.$^{-2}$min.$^{-1}$ and 50×10^{-8} g.cm.$^{-2}$min.$^{-1}$ (one percent level).

There was no significant difference in the weight of the roots for plants grown in the clay loam. Root weight of plants grown in the sandy loam was significantly different at the five percent level for oxygen diffusion rates of the two extremes. The root-shoot ratio was significantly different at the one percent level for oxygen diffusion rates of the two extremes on the clay loam, but not with the sandy loam.

TABLE II

The Effect of Oxygen Diffusion Rates on the Weight of Roots and Shoots and on the Root-Shoot Ratio of Beans (*Phaseolus vulgaris* var. Sanilac) grown in the Greenhouse (Experiment 2).

Weight of Shoots

Sims Clay Loam: Oxygen Diffusion Rates $gm \times 10^{-8} cm^{-2} min^{-1}$	Weight in Grams	Breckenridge Sandy Loam: Oxygen Diffusion Rates $gm \times 10^{-8} cm^{-2} min^{-1}$	Weight in Grams
5	57	14	45
14	59	40	49
31	82*	53	64*
50	149**	62	75**
L.S.D.	24.4 (5% level)		18.3 (5% level)
	32.5 (1% level)		24.1 (1% level)

Weight of Roots

Sims Clay Loam: Oxygen Diffusion Rates	Weight in Grams	Breckenridge Sandy Loam: Oxygen Diffusion Rates	Weight in Grams
5	14.0	14	15.1
14	13.3	40	15.2
31	12.5	53	17.5
50	12.5	62	20.0*
L.S.D.	3.3 (5% level)		4.3 (5% level)
	4.2 (1% level)		5.1 (1% level)

Root-Shoot Ratio

Sims Clay Loam: Oxygen Diffusion Rates	Ratio	Breckenridge Sandy Loam: Oxygen Diffusion Rates	Ratio
5	0.25	14	0,33
14	0.20	40	0.31
31	0.15	53	0.29
50	0.08**	62	0.30
L.S.D.	0.11 (5% level)		0.09 (5% level)
	0.17 (1% level)		0.14 (1% level)

* Significant difference at 5% level
** Significant difference at 1% level

ROOT-ROT INDEX CLASSES

An evaluation of the data (Table III) revealed that there was considerable variation in the degree of root-rot based on the variation of oxygen diffusion rates in the two soils. Root-rot was least severe on plants growing in oxygen diffusion rates of 50 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ and higher. On the contrary, the most severe cases occurred where there were oxygen diffusion rates of 14 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ or lower for both soils. Not only were these differences significant but quite spectacular and had a direct effect upon the vegetative state of the plants.

The figures for this experiment grouped the root-rot infections into four of the six categories. The greatest number fell in index 3 followed by 2, 1 and 4. No plant was found that could be placed in either zero or five although a few came very close to the borderline. There was an average of four plants in category 2 and seven in category 3 where the oxygen diffusion rate was 14 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ (sandy loam). Data for the same size pots of clay loam with oxygen diffusion rate of 5 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ showed an average of eight for category 3 and eight for category 4. Another comparison was drawn between pots of similar sizes containing the two soils. For the 12-inch pot of sand with an oxygen diffusion rate of 62 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$, there was a root-rot average of 2.3 in category 1, 3.3 in category 2 and 2.3 in category 3, while the clay loam with an oxygen diffusion rate of 31 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ had none in category 1, 2.3 in category 2 and 8 in category 3.

As shown by the data in Table III the incidence of root-rot was markedly affected by the height of the soil column which in turn was indicative of the oxygen diffusion rate. This occurred with the plants growing in the two soil types. The data showed that the root-rot was more severe in the clay loam soil than in the sandy loam soil and that the difference in the two extremes was greatest with the clay loam. The extremes were from 39 to 60 percent with the clay loam soil as compared from 41 to 52 percent with the sandy loam soil. The respective oxygen diffusion rates ranged from 5 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ to 50 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ and from 14 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ to 62 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$.

In expressing the degree of root-rot in percentage, standard values were assigned the index classes. Since index 5 is the most severe of the classes where all the roots have been affected and are completely functionless a value of 100 percent was assigned. Index class 0 thus has no percent root-rot,and the intermediate indices 1, 2, 3 and 4 were assigned values of 20, 40, 60 and 80 percent respectively.

On the Sims clay loam plants that were grown under oxygen diffusion rates of 5 x 10^{-8}g.cm.$^{-2}$min.$^{-1}$ and

14×10^{-8}g.cm.$^{-2}$min.$^{-1}$ showed no significant difference in the degree of root-rot at the five percent level. Significant difference showed up at this level between plants grown in oxygen diffusion rates of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and also between diffusion rates of 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$. At the one percent level there was significant difference between plant roots from the highest oxygen diffusion rate and those from each of the lower diffusion rates.

For the Breckenridge sandy loam there was significant difference at the five percent level between each treatment and at the one percent level between plants with the lowest oxygen diffusion rate and each of the higher rates.

TABLE III

The Incidence of Root-Rot as affected by Oxygen Diffusion Rates in Beans planted in the Greenhouse in Sims Clay Loam and Breckenridge Sandy Loam.

Sims Clay Loam		Breckenridge Sandy Loam	
Oxygen Diffusion Rates $g. \times 10^{-8} cm^{-2} min^{-1}$	Root-Rot Indices #	Oxygen Diffusion Rates $g. \times 10^{-8} cm^{-2} min^{-1}$	Root-Rot Indices #
5	60	14	52
14	62	40	47**
31	54**	53	44**
50	39**	62	41**
L.S.D. 5.3 (5% level)		3.0 (5% level)	
7.7 (1% level)		4.4 (1% level)	

\# Values based on root-rot indices expressed in percent:
0 = 0%; 1 = 20%; 2 = 40%; 3 = 60%;
4 = 80%; 5 = 100%.

* Significant difference at 5% level

** Significant difference at 1% level.

EXPERIMENT 3

The planting procedure of Experiment 2 was followed and germination of the seeds was as successful as in that experiment.

Results and Discussion

The vegetative development was similar to that of the previous experiment but the weight of the roots and shoots showed higher values. This was attributed to the fact that the experiment was terminated a week later and the plants had more time for development. The roots, too, were allowed a longer time before the inch of water was maintained.

The previous average weight of all the roots grown in the sandy loam was 15.3 grams,and of the shoots 50.6 grams. The figures for the clay loam were: roots 10.6 grams and shoots 70.7 grams. The repeated experiment produced an average weight in grams of the roots and shoots of the plants grown in sandy loam to be 19.3 and 88.0 respectively, and for plants grown in the clay loam 15.8 and 128.3 respectively. The figures for the roots, shoots and root-shoot ratio for the different treatments are given in Table IV.

TABLE IV

The Effect of Oxygen Diffusion Rates on the Weight of Roots and Shoots and on the Root-Shoot Ratio of Beans (*Phaseolus vulgaris* var. Sanilac) grown in the Greenhouse (Experiment 3).

Weight of Shoots

Oxygen Diffusion Rates $g. x 10^{-8} cm^{-2} min^{-1}$	Weight of Shoots in Grams	Oxygen Diffusion Rates $g. x 10^{-8} cm^{-2} min^{-1}$	Weight of Shoots in Grams
5	46	14	74
14	132**	40	102
31	213**	53	148**
50	278**	62	140**
L.S.D.	36.4 (5% level) 53.1 (1% level)		30.3 (5% level) 42.7 (1% level)

Weight of Roots

5	18.1	14	24.6
14	19.5	40	23.1
31	20.0	53	22.3
50	21.5*	62	24.5
L.S.D.	2.8 (5 level) 3.6 (1% level)		3.3 (5% level) 4.7 (1% level)

Root-Shoot Ratio

5	.38	14	.33
14	.17*	40	.25
31	.09**	53	.16*
50	.08**	62	.18
L.S.D.	2.0 (5%Level) 2.6 (1% level)		.16 (5% level) .22 (1% level)

* Significant difference at 5% level

** Significant difference at 1% level.

There was marked increase in the weight of shoots with increasing oxygen diffusion rates for both soil types. For the plants grown on the Sims clay loam there was significant difference at the one percent level between each treatment. No significant difference was obtained between plants grown in the sandy loam with oxygen diffusion rates of 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 40×10^{-8}g.cm.$^{-2}$min.$^{-1}$ A significant difference was obtained between plants grown in this soil at oxygen diffusion rates for the two extremes and for the highest two (one percent level). The weight of roots was fairly uniform with no significant difference for the sandy loam, but at the five percent level a significant difference was obtained between plants grown in clay loam soil with the two extremes of oxygen diffusion rates.

The root-shoot ratio showed significant difference at the five percent level between plants grown on the clay loam at oxygen diffusion rates of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$, and at the one percent level between plants grown where the oxygen diffusion rates were 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and between the extremes. There was also decrease in the root-shoot ratio with increasing height of pots. For the sandy loam the only significant difference was obtained between plants grown where the diffusion rates were 14×10^{-8}g.cm.$^{-2}$min^{-1} and 53×10^{-8}g.cm.$^{-2}$min.$^{-1}$ (five percent level).

In the previous experiment the data for root-rot showed that, for the sandy loam soil, the greater number of cases fell in index classes 2 and 3 and that there was only one case recorded in index class 4. The latter experiment showed that the greater values were still in index classes 2 and 3 and a small percentage in index class 4. For the clay loam in the previous experiment the greater number of cases fell in index class 3 with about equal numbers in classes 2 and 4. In this experiment, more than 25 percent of the cases fell in index class 5 and most of the others in classes 3 and 4. This could be attributed to the extension of time before harvesting. As was observed previously, the more severe root-rot cases developed where oxygen diffusion rates were lowest. The values are recorded in Table V.

A significant difference was obtained between plants grown in the clay loam with oxygen diffusion rates of 5×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$ (five percent level); between those with oxygen diffusion rates of 14×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and 31×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and between the extremes at the one percent level. There was significant difference between plants grown in the sandy loam with oxygen diffusion rates of 62×10^{-8}g.cm.$^{-2}$min.$^{-1}$ and each of the lower diffusion rates (one percent level).

It is clearly indicated that as the oxygen diffusion rate increases the percentage of root-rot decreases for both soil types.

TABLE V

The Incidence of Root-Rot as affected by Oxygen Diffusion Rates in Beans planted in the Greenhouse in Sims Clay Loam and Breckenridge Sandy Loam. (Experiment 3).

Oxygen Diffusion Rates $g.x\ 10^{-8}cm^{-2}min^{-1}$	Root-Rot Indices #	Oxygen Diffusion Rates $g.x\ 10^{-8}cm^{-2}min^{-1}$	Root-Rot Indices#
5	95.0	14	57.0
14	79.0*	40	56.0
31	57.0**	53	52.0**
50	52.0**	62	43.5**
L.S.D.	13.5 (5% level)		2.7 (5% level)
	19.6 (1% level)		3.9 (1% level)

\# Values based on root-rot indices expressed in percent:
0 = 0%; 1 = 20%; 2 = 40%; 3 = 60%
4 = 80%; 5 = 100%.

* Significant difference at 5% level

** Significant difference at 1% level.

SUMMARY

The study was initiated to investigate whether lack of oxygen was associated with the incidence of root-rot in beans (Phaseolus vulgaris var. Sanilac). The experiment was carried out on two soil types, Sims clay loam and Breckenridge sandy loam. The soil oxygen diffusion rate was measured by using the platinum micro-electrode method of measuring oxygen diffusion to determine the supply of oxygen of the soils.

The depths of soils in the pots for the clay loam were 5, 7, 10 and 15 inches, and for the sandy loam 5, 6, 8 and 10 inches. The treatments were replicated six times. After successful germination was established, noticable differences in growth developed as a result of variation in oxygen diffusion rate.

The root-shoot ratio was exceptionally narrow where the oxygen diffusion rate was least, while a wide ratio marked pots which were better aerated. The root-rot index showed much milder infection from pots with high diffusion rates compared with those with lower values. This was true for both the sandy loam and the clay loam. An analysis of variance showed the results to be significant at both the five and one percent levels.

On repeating the experiment, a similar growth pattern was noticed and the root-shoot ratio followed

similar pattern as noted above. However, the values for root-rot incidence increased significantly and this was attributed to the longer period of vegetative growth. As previously observed, the more severe cases developed in pots with the lowest oxygen diffusion rates.

CONCLUSION

A relationship exists between oxygen diffusion rate and seed germination. The very low rate of oxygen diffusion in the pots when the first seeds were planted resulted in decay of the seeds. Crop development potentialities, too, have direct relationship with the oxygen diffusion rates. This was verified by the weight of the shoots in the various sizes of pots. Under low oxygen diffusion rates a severe root-rot condition was found in the plants grown in the short soil columns. An adequate oxygen diffusion rate contributed to long root hairs as was found in the tallest soil columns. These penetrated the soil and eventually formed a network at the bottom, Inadequate oxygen diffusion resulted in the production of more root hairs which were short with a tendency to grow horizontally.

Low oxygen diffusion rates ($31 \times 10^{-8} g.cm^{-2} min^{-1}$ and lower) resulted in a decrease in water uptake as was evidenced in the physiological condition of the plants in the very short pots. Finally and most important, considerable evidence was present to indicate that low oxygen diffusion rates resulted in root decay, intensity being proportional to the oxygen supply.

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