EFFECT OF SOIL WATER CONTENT AND OXYGEN DIFFUSION RATE ON GROWTH OF POTATO SETS

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By

Lloyd Peter Jackson

A THESIS

Submitted to the College of Agriculture of Michigan State
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in partial fulfillment of the requirements
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Department of Soil Science

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ABSTRACT

Potato sets were planted in Oshtemo sand soil columns of eight different heights. They were sub-irrigated. The soil water content at the surface were inversely proportional to the height of the soil column. Oxygen supply in the shorter columns was limited because of excess water.

The platinum microelectrode method for measuring oxygen diffusion in soil was used to determine the rate of oxygen supply in the various treatments. Oxygen diffusion rate increased and moisture in the surface decreased with height of soil column above the free water surface.

Sprouting and growth of the sets as measured by emergence rate and dry matter production were materially affected by the water content and oxygen diffusion rate in the soil.

Cut potato sets were also held in water saturated soils for periods of one to six days and at temperatures of 50°, 65°, 70°, and above 85°F. The detrimental effects of flooded soils on potato sets increased with increases in temperature.

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I. INTRODUCTION

Air, with its accompanying oxygen content is essential to the well being of higher forms of plant life.

The indispensable function of oxygen in plant life has been proposed by Bonner et al (7) who point out that vital growth processes such as water uptake and nutrient accumulation proceed with an expenditure of energy which is dependent on aerobic metabolism. They have concluded that the energy consuming processes within living organisms cannot proceed when oxygen is not available to assist in respiration and metabolism which provides the energy necessary for the discharge of vital body work functions. Heald (33) states that when the oxygen supply to living plant tissues is reduced or withheld they are likely to smother with progressive death of various parts of the tissues. This sub oxidation and the accompanying anaerobic respiration doubtless contributes to the activity of certain plant diseases (33). Under limited oxygen supply the damaged or dead tissues are susceptible to putrefactive decay and consequently are invaded by rot producing organisms (33). A typical example of such condition is potato blackheart. This disease is believed to be the result of derangement of normal physiological processes because of unfavorable environmental conditions and has been shown to occur when tubers do not obtain oxygen to supply respiratory demands (4).

Because deficiency in soil aeration is frequently suggested as an agricultural problem, and is advanced as a reason for the failure of certain species to grow, this series of trials was set up to determine, quantitatively, the amount of oxygen required for statisfactory growth during the early life of the crop being studied. The crop chosen for observation was the white, or Irish potato, (sp. Solanum tuberosum).

The potato is grown under a rather wide variety of soil conditions but does best on a moist soil with ample aeration (54). Loam, fine sandy loam, or silt loam soils with especially good under-drainage are most desirable (54). Detailed experimental studies of the soil air requirements for potato growth have emphasized the fact that "a considerable volume of air is required for the well being of the potato" (55).

Space occupied by air in a given soil increases or decreases inversely with moisture fluctuations and it is believed that many problems of limited aeration are bound up with the problems of soil water (2). In these experiments depth to water table was used to develop the variations of air pore space in the soil.

The physical process of diffusion is considered the most important means by which interchange of air in the soil is brought about (8). A convenient and relatively rapid technique for the determination of oxygen diffusion within the soil was recently developed (39, 41) and this method was used to determine the optimum soil oxygen diffusion rate for satisfactory sprouting and growth of the potato.

In a supplementary trial the result of submerging potato sets in water saturated soil at four levels of temperature and for periods of one to six days was studied. Appearance on removal from submergence and in a subsequent green sprouting test were the criteria used to

evaluate the effects of these treatments.

II. LITERATURE REVIEW

A. Plants in General

The dependence of root development on soil air and its oxygen content has been the subject of many research problems. The vital role of soil aeration in the life of plants has been demonstrated in the work of such investigators as Livingston and Free (14), Cannon (13, 14, 15, 16), Cannon and Free (17) and Clements (19). Their findings have been confirmed in greater detail in the more recent investigations of Hutchins (36), Loehwing (45), Henderson (34), Boynton (6), Kramer (38), Erickson (27), and Hopkins (35). The texts published by Baver (2), Miller (50) and Meyer and Anderson (49) are also most enlightening with regard to the essential nature of soil oxygen in the life of plants.

Cannon (13) demonstrated that total root growth, and rate of root growth, decreased with low oxygen supply and concluded that composition of the soil air was of less significance in aeration than was the rate at which air flowed through the soil.

In seed germination studies Hutchins (36) observed that some weeds germinated well with a slow oxygen supply while others required a very rapid supply.

Loehwing (45) found that for optimum growth most roots depended on free soil oxygen, and the improper composition of soil air resulted in delay or failure of growth processes.

A close correlation between water absorption and respiration rate in maize seedlings was shown by Henderson (34) who concluded that the retarding effect of poorly aerated soils upon absorption of water may be due in part to the toxic effect of carbon dioxide accumulation on the root cells. Kramer (38) also concluded that rapid reduction of water uptake by plants in poorly aerated media was probably caused by a high concentration of carbon dioxide which he found had an unfavorable effect on the protoplasm and protoplasm membranes.

Boynton (6) in his studies with apple tree growth found that higher oxygen levels might be necessary for the production of new rootlets than for the maintenance of life in existing roots. Erickson (27) working with tomato plants found that insufficient oxygen rather than excess carbon dioxide was responsible for the characteristic differences observed between aerated and non-aerated solutions.

The overall growth response of several plants to low partial pressures of oxygen in the soil atmosphere was observed by Hopkins (35). He found that root growth ceased at an oxygen content below 0.5 percent in the air surrounding the roots and suggested that quantitative studies of soil aeration would be more desirable than the present qualitative studies.

The recent research work of Lemon (39), and Lemon et al (41) has resulted in the development of apparatus by means of which quantitative soil oxygen determinations may be obtained. Using this apparatus Lemon and Erickson (40), Archibald (1), Cook et al (20) and Wiersma and Mortland (60) have determined the soil oxygen requirements for several plant species. They have also shown that plant growth is dependent on and closely correlated with oxygen movement within the soil. Reduced growth was noted in all trials when oxygen was in limited supply. The use of calcium peroxide as an oxygen supplier for three types of soil in which sugar beets were grown was effective in raising the oxygen status of the soils and the improved plant growth was attributed to the beneficial effect of the oxygen released from the peroxide (60).

B. Potatoes

1. Laboratory investigations. Researches into the life and growth habits of the potato (Solanum tuberosum) have resulted in an extensive amount of literature covering all phases of the ontogeny and development of this important plant species and the texts of Burton (9), Stuart (56), and Hardenburg (29) supply good reference material.

The potato is recognized as a type of plant storage tissue unable to endure confinement which restricts or limits the air supply (55). It is known that the end result of limited aeration is the appearance of the disorder called blackheart followed by soft rot resulting from the invasion of damaged or diseased tissue by putrefactive organisms (33).

Bartholomew (4) recognized the diseased condition known as blackheart and determined that overheating was responsible for the damage discovered in potatoes shipped in heated railway cars. In laboratory trials he showed that heating tubers to 38° to $50^{\circ}C$ for 14 to 18 hours brought about changes in the respiration rate necessitating more oxygen than was available (4).

Stuart and Mix (55) confined potato tubers in hermetically sealed jars and were able to develop blackheart symptoms in 10 to 12 days at 30°C. Their work demonstrated that the air supply, as well as temperature is a factor in the production of blackheart. Bennet and Bartholomew (5), and Davis (23), as well as Singh and Mather (53), all concluded that blackheart of Irish potatoes is a good example of the detrimental effects that may be initiated by conditions of anaerobic respiration. Their general conclusion was that an accumulation of carbon dioxide and a depletion of oxygen in potato tissue preceded the appearance of blackheart. They suggested that the disease is attributable to high respiratory activity and the failure of gas exchange to keep pace with respiration rate.

Hardenburg (30) submerged dormant potato tubers of the Sebago and Kathadin varieties for periods up to 10 days at temperatures of 40°, 50°, and 70°F, followed by green sprouting tests. Normal sprouts developed on tubers submerged 10 days at 50° and 40° but at 70°F dead eyes were general after three or four days. He considered temperature to be the critical factor in damage caused by flooding.

Ross and Robinson (52) also observed the effect of immersion of potato tubers. Using sea water as well as fresh water they immersed potatoes for periods up to three days. At 56°F the dormancy period was shortened, while prolonged immersion resulted in soft rot of the tubers and injury to the sprouts. When fresh water was used, severe rot was observed in two days at 50°F.

Injury to and death of seed pieces at various temperatures and in controlled or limited atmospheres was also demonstrated by Denny (24). In his tests severe injury resulted when seed pieces were held in closed containers at 35°C for 24 hours. Temperatures between 20°C and 30°C caused less injury. A high respiration level and accumulation of carbon dioxide were said to account for death of the tubers.

2. Field investigations. Growth failure because of seed piece decay is known to be the cause of weak and unthrifty stands of potatoes. Various factors are assigned as reasons for this and many observations and studies have attributed the trouble to physical conditions of the environment.

Jones (37) found little variation between varieties so far as seed piece decay was concerned. He found the causative organisms to be putrefactive bacteria which, generally speaking, are incapable of infecting the tissues of sound healthy tubers. Preventive measures suggested are those of soil sanitation through good drainage and aeration.

Reduced yields of potatoes in some Ohio experiments have been attributed by Bushnell (11) to the unfavorable physical conditions of the soil brought on by faulty rotation methods. Yields were increased following the adoption of a rotation which included sod crops and which resulted in improved physical conditions of the soil (11).

Clark (18) conducted experiments to determine to what extent, if any, tuber growth is influenced by soil type. He planted seed on a very heavy clay (Billings clay loam), a clay loam (Fort Collins loam), and a sandy loam (Colorado fine sandy loam). The lowest production of tubers with respect to both number and weight per hill was on the heaviest soil, while the highest numbers and yield were produced on the lightest soil.

Dunn (25) planted potatoes in soils containing 50, 60 and 70 percent moisture and within temperature ranges of 14° to 15°C and 18° to 20°C. The most noteworthy result reported was that cold temperature retarded sprouting.

McLeod (48) suggested that both soil and weather may be responsible for conditions which favor tuber rot. He observed instances where total or partial rotting of tubers appeared to be caused by soil that was too wet or too dry. In a previous report (47) he stated that planting in cold wet soil should be avoided because such conditions favor the rotting of the seed pieces.

Working on Wooster silt loam, Bushnell (10) laid tile lines in the ground just below the root zone. Increased root development and yield obtained on that area were attributed to the improved aeration status of the soil because of air movement through the tiles and into the surrounding soil. In other yield trials on Wooster and Canfield silt loams (12) satisfactory yields were reported with an average pore space of 49 percent, while considerably lower yields were reported when pore space was only slightly less than 49 percent. Bushnell concluded that this might be the minimum pore space requirement for potato growth on those soils (12).

3. Irrigation investigations. Water requirements for optimum potato production are quite high and a study of yields from irrigated and non-irrigated plots illustrated the advantages of increased water supply in locations of low or moderate rainfall (9). There is also a limited amount of information on the harmful effect of excessive amounts of irrigation water.

Harris (31) conducted experimental work on irrigation at various stages of growth and at several rates of watering. The lowest yields were obtained when the land was watered after the potatoes were planted and before the plants had emerged. His conclusion was that water applied at that time was injurious and that the period just after planting may be quite critical in the life of the plant.

Edmunston (26) obtained good yields from irrigation at planting time when he supplied considerable moisture to the soil that came in contact with the seed piece but left the top 3 or 4 inches above the seed piece as dry as possible. He observed that the soil was not flooded.

Hardenburg (28) in greenhouse experiments and Clark (18) and Werner (59) in field trials concluded that irrigation during the growing season is favorable to potato growth. Additional yields were obtained as water supply was increased; however, Clark found too frequent watering harmful and suggested the possibility of reduction in yield because of excessive irrigation.

In investigations of optimum and minimum requirements Harris and Pitman (32), in Utah, found that low yields of potatoes were obtained with less than 10 inches of water and that more than 25 inches also reduced yields. On the other hand McGillvray (46) reported that 30 to 35 inches of water produced maximum yields under the soil conditions of his trials. Cykler (22) obtained high yields of potatoes when the soil water content was maintained at a high level throughout the growing season. He pointed out that the water content of the soil was never below one half the difference between moisture equivalent and the wilting point.

4. Aeration measurements. Many previous measurements of aeration have been based on instantaneous determination of the air or oxygen status of the soil. The inadequacy of this type of measure is freely admitted, and the importance of rate of oxygen diffusion rather than original supply has been recognized in the recent literature of Cannon (13), Hutchins (36), Taylor (57), Raney (51), and Lemon and Erickson (40).

The investigations of Lemon and Erickson (40) provided a very efficient and practical method for the measurement of oxygen diffusion. Using a relatively simple and easily manipulated platinum electrode they succeeded in measuring oxygen diffusion rate and obtained a good correlation between rate of oxygen movement and growth of tomato plants. It was found that a diffusion rate in the liquid phase of less than 30 grams x 10^{-8} per square centimeter per minute at the 8 inch depth may be critical for tomato plants.

In tests with sugar beet Wiersma and Mortland (60) found that a diffusion rate of between 20 and 30 grams x 10^{-8} per square centimeter per minute may be the critical range for sugar beet growth.

Cook et al (20) showed that a minimum of 45 to 50 grams x 10^{-8} per sqare centimeter per minute is necessary for the growth of snapdragon plants.

Archibald (1) using a similar technique to that of Lemon and Erickson pointed out the effect of limited aeration on the growth of sugar beets and oats as successive crops in the same soil.

Erickson[1] observed recently that the water content of field soil can be related to the vigor and growth of potato plants growing in that soil. On June 16, 1955, he found that potato plants on one section of an experimental plot at Michigan State University were wilted while plants farther along in the same row appeared quite normal. Tests made on the two areas indicated that the wilted plants were in soil containing 20 to 21 percent water while the soil on which the plants appeared normal was found to contain only 15 percent water. The aeration rates for the two soils were respectively 37 x 10^{-8} grams and 56 x 10^{-8} grams of oxygen per square centimeter per minute.

About six weeks after this observation the mature plants were examined. Plate 1 shows representative plants growing on the two sections of the same plot. On Plate 2, Fig. 3 shows the growth of the tops and yield of small tubers for plant number 1 which grew on the wet soil and this is in sharp contrast to the plant in Fig. 4 with more luxuriant growth and much larger tubers developed on the somewhat drier soil with

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[1]Unpublished data, collected on an experimental plot area, Michigan State University. Data on file with Dr. A. E. Erickson, Associate Professor, Soil Science Department, Michigan State University.

improved aeration. It seemed that the critical aeration value for potatoes growing in this Michigan field in the year 1955 was between 37 and 56×10^{-8} grams of oxygen per square centimeter per minute.

PLATE 1

PLANTS AT HARVEST

July 18, 1956

Fig. 1.

Note the stunted plants because of excessive soil water during the growing season.

Fig. 2.

Plants of normal size, soil conditions were more favorable to growth than in Fig. 1.

PLATE 2

YIELD OF PLANTS AT HARVEST

July 18, 1956

Fig. 3.

Stunted plant and small tubers. The results of excessive soil water during the growing season.

Fig. 4.

Normal sized plants with good tuber growth. The result of more favorable soil conditions than for those plants shown in Fig. 3.


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III. EXPERIMENTAL STUDIES

A. Aeration Experiment

1. Greenhouse. This experiment, designed to study the related effect of soil water and soil aeration on the establishment and initial growth of the common potato was set up in the Sugar Beet Greenhouse at Michigan State University, East Lansing, Michigan. The crop was grown during the summer months when extremely hot weather conditions prevailed. House temperatures were almost daily above 100°F for several hours.

2. Soil. The soil used for this experiment was Oshtemo sand, obtained from a farm in the Rose Lake Conservation Area, located in Clinton County, Michigan. The soil was passed through a quarter inch mesh screen to remove all coarse material, then was thoroughly mixed and placed in pots.

3. Pots. Glazed tile eight inches in diameter were cut into 4, 6, 8, 10, 12, 16, 20, and 24 inch lengths. The tile were made into pots by covering one end (to be the bottom) with cheesecloth and placing them in galvanized pans 2 inches in depth. The screened sand was packed uniformly in each of the pots and as packing proceeding the soil was thoroughly saturated with a complete nutrient solution. Each pot was filled to within one half inch of the upper rim. The galvanized pan was filled with water, thereby providing constant level sub-irrigation and a source of capillary water for each soil column.

4. Design of experiment. The experiment consisted of eight replications of the eight pot heights with a total of sixty-four pots in all. The pots were arranged in the greenhouse in an eight by eight Latin square design.

5. Seed stock. Sebago seed potatoes grown in the fields at Michigan State University in the crop year 1954 were obtained from the common storage facilities of the Farm Crops Department, Michigan State University.

Pieces of uniform size each having at least two eyes and weighing 45 (± 2), grams were cut and placed in a cool cellar for forty-two hours before being planted.

6. Planting. On June 24, 1955, the sets were planted, one to a pot, at a depth of two inches. Sets were covered with about one inch of soil.

It was thought that surface watering would be unnecessary during the trial, but because of the high atmospheric temperature and associated excessive evaporation, top watering was begun after the two-week emergence period and was continued at two-day intervals until the completion of the experiment.

7. Duration. The experiment ran for thirty-four days with the main interest centered on the reaction of the mother set to the various conditions established within the soil of each treatment. Pre-emergence effects were observed for fourteen days after planting and growth of

those plants which came through the ground was noted for a further twenty days in the post-emergence period.

8. Plant measurements. The experiment was terminated when the more advanced plants had reached the full bloom stage.

Individual emergence dates were noted for all replicates of each treatment. The date of emergence was recorded as the day on which fifty percent of the plants were expanding their first leaves.

Individual height measurements were taken at two-day intervals following the date of total emergence. The average length, in centimeters, of all stems on each plant was used as the index of growth for that plant. The plants were harvested on July 28, at which time total growth was determined by weighing the above ground portion of all living plants. Measurement of root growth was also attempted but owing to their fragile nature a considerable portion of the smaller rootlets were broken away in washing out the soil. For this reason, the root measurements were considered unsuitable and are not included in this report.

9. Soil measurements. The platinum microèlectrode method, designed and used by Lemon (39), Lemon and Erickson (40, 41), and recently modified by Van Doren (58) was used to obtain the oxygen diffusion rate in each set of pots. Determinations were made at weekly intervals.

Five electrodes inserted in the soil of each pot to a depth of 2 inches were used to obtain initial and final current readings. From these readings the rate of oxygen diffusion toward the surface of the electrodes was calculated. As there seemed to be a steadily decreasing reading in each treatment as the experiment progressed, the average readings were calculated separately for the pre-emergence and post-emergence periods.

10. Laboratory measurements. Moisture retention and non-capillary porosity were determined in the laboratory using the Leamer and Shaw tension table (42). Metal cores one inch deep and having a diameter of three inches were filled with the same soil. After saturation with water the losses in weight at tension increments corresponding to the heights of the eight pots were used to calculate percent air filled pores in the surface layers of the soil in each treatment. The percent moisture retained in the various porosity ranges was calculated on an oven dry basis.

11. Temperature experiment. In addition to the previous experiment a test was performed to determine the length of time before breakdown of tissue occurs when potato tubers are immersed in saturated soil at various constant temperatures.

Twenty-four lots of four cut tubers each were placed in separate pots containing Oshtemo sand. The soil in all pots was completely flooded with water immediately after the sets were planted. Six lots were placed in each of four locations having the following constant temperatures (1) 50°F, (2) 65°F, (3) 70°F and (4) in the greenhouse where the temperature varied with the normal daily fluctuation between 75° and 85°F at night to a maximum greater than 100°F during the daytime.

Starting one day after planting one pot was removed from each temperature location every day for a period of six days. Two of the tubers in each of the four pots were taken from the soil, examined, and placed on a covered tray in a basement location for further observation and green sprouting while the other two tubers were left in the soil. At the same time a plug in the base of each of the four pots was removed to permit drainage of excess water. Each day thereafter a pot was taken from each of the four temperature locations, two sets were removed and placed on trays for the sprouting test, and then the pots were drained and placed on a bench in the greenhouse for observation of the two sets remaining in the soil.

Emergence of sprouts from the sets in the soil held under the greenhouse conditions was noted over a period of two weeks. This time was considered adequate for any living tubers to sprout and send up shoots.

The growth of sprouts, and the occurrence of decay on the sets stored in the basement were observed for one week.

IV. RESULTS AND DISCUSSION

A. Aeration Experiment

The pots shown on Plate 3 were arranged to illustrate the comparative size of the soil columns. The shortest pot extended two inches above the free water surface while the top of the highest column was twenty-two inches above the water in the pans. The pots in Treatments 1 to 5 inclusive increased in height by two inch increments while those in Treatments 6, 7, and 8 changed by four inch treatments.

Plate 3 also shows some of the plants which were grown. Growth was practically non-existent in Treatments 1 to 4 and the two plants shown were the only ones living from the thirty-two sets planted in this group. It is clear that the soil condition in the first four treatments was decidedly unfavorable to the sprouting and growth of the potato sets. On the other hand, the plants shown in pots 5 to 8, Plate 3, were chosen as representative of the good stand of plants obtained. In columns 5 to 8 only three of the thirty-two sets in this group failed to produce living plants and from this we may conclude that soil conditions in these four treatments were favorable to sprouting and growth.

Certain soil conditions in the eight treatments are given in Table 1. The data relating to laboratory determinations of non-capillary porosity, and tests of surface moisture at tensions corresponding to those in the various soil columns are presented. The moisture content as determined from samples of soil taken in the greenhouse at the conclusion of the experiment are also given. The almost complete filling

PLATE 3

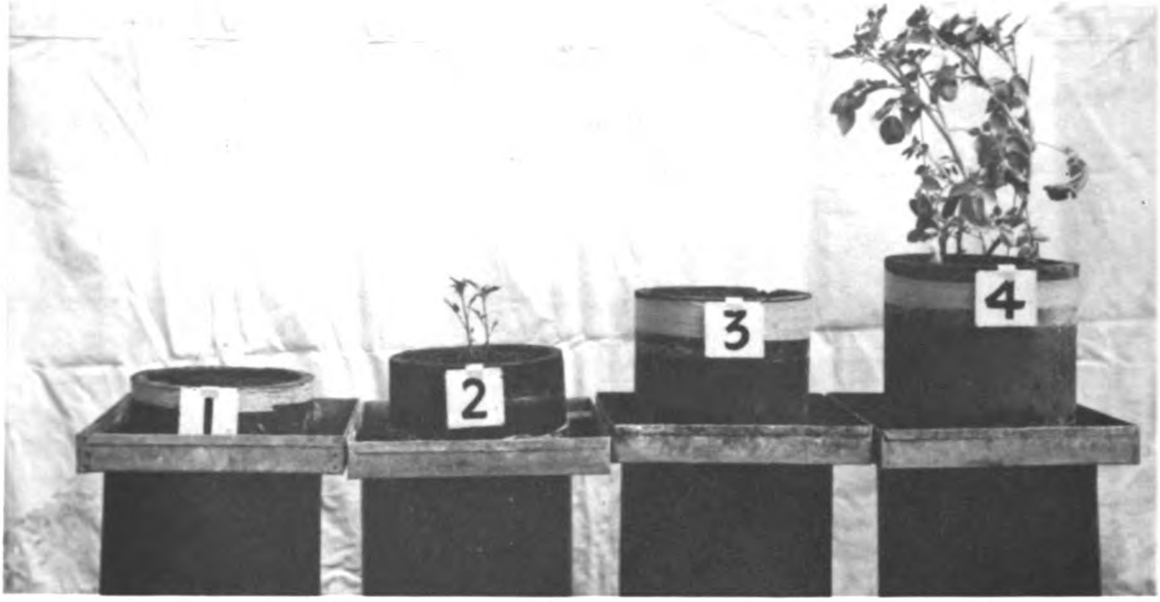
Fig. 5.

Showing heights of the pots and plants from the treatments.

There were no plants in Treatments 1 or 3.

The plants shown in pots 2 and 4 were the only ones surviving in these two treatments.

The plants in Treatments 5, 6, 7 and 8 are representative of the growth obtained in these four soil columns.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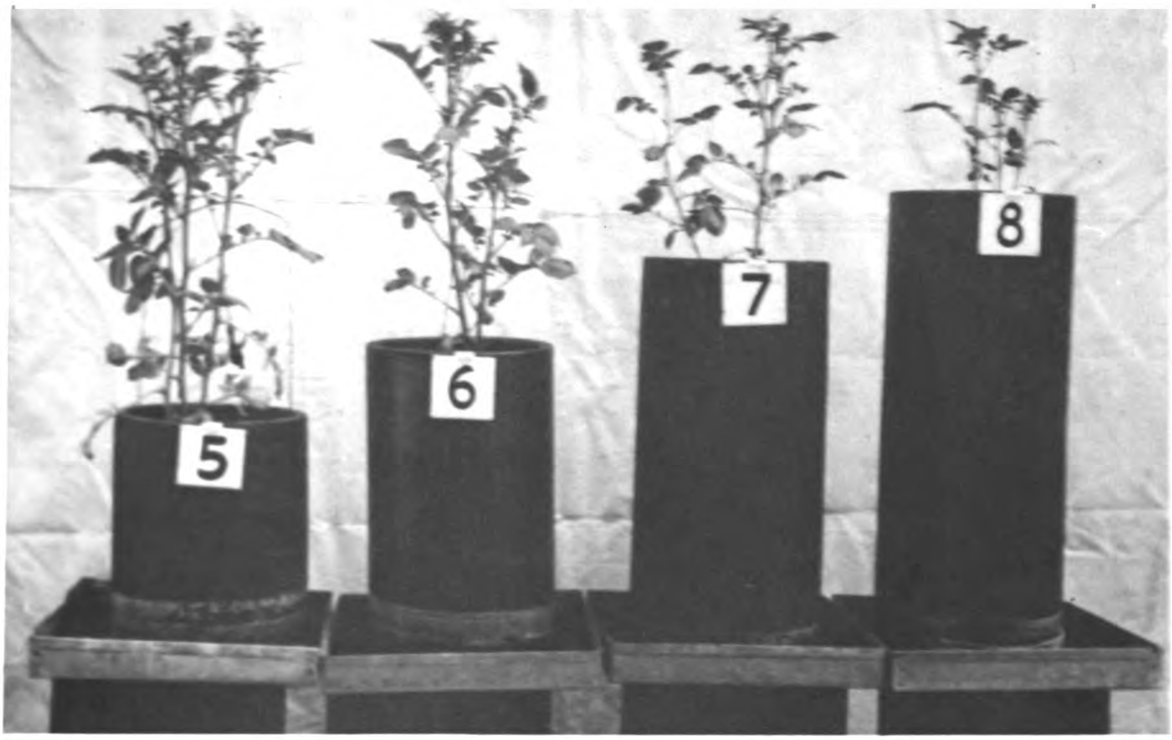
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TABLE 1

THE EFFECT OF HEIGHT OF SOIL COLUMN ABOVE THE WATER TABLE ON THE NON-CAPILLARY POROSITY AND THE MOISTURE CONTENT OF THE SURFACE SOIL

Treatment number	Soil column inches	Soil Measurements		
		Laboratory cores[1]		Greenhouse pot soils[2]
		Non-capillary porosity %	Moisture content %	Moisture content %
1	2	2.4	25.4	x
2	4	4.8	23.8	x
3	6	7.1	22.4	x
4	8	9.1	21.0	19.0
5	10	12.2	19.0	14.1
6	14	16.7	16.1	8.9
7	18	20.7	13.0	8.1
8	22	22.9	12.0	6.8

[1]Determined on Leamer and Shaw tension table.

[2]Soil samples obtained from surface soils of each treatment at the conclusion of the experiment.

xNo sample.

of soil pores with water in Treatment No. 1 is indicated. In this case the low value of 2.4 percent non-capillary porosity is brought about by a moisture content very near the saturation point. Progressive increases in non-capillary porosity and at the same time a reduction in soil moisture were obtained with increasing heights of the soil columns above the water line.

The increases in porosity are indicated in the laboratory determinations of pore space which ranged from 2.4 percent in Treatment No. 1 to 22.9 percent in Treatment No. 8 and are associated with a decrease in water content from 25.4 percent to 12.0 percent. Data in Table 1 show that the moisture content of the soil under greenhouse conditions was somewhat less than for the ideal conditions as calculated in the laboratory. The difference was 4.9 percent for Treatment No. 5 while for Treatments No. 6, 7, and 8 the respective differences were 7.2, 4.9, and 5.2 percent. These lower values obtained in the greenhouse were no doubt caused by the excessive temperature and associated high evaporation rate which prevailed during the time of the experiment and the fact that the plants were extracting moisture from the soils in which they were growing. Tabulated data presented later in this discussion reveal that the relatively low soil moisture contents found in Treatments No. 7 and No. 8 impose some limitations on the interpretation of the oxygen diffusion data.

The rates of oxygen diffusion within the soils of the various treatments were determined for the two-week pre-emergence and the three-week post-emergence periods and are shown in Table 2. All treatments showed

TABLE 2

THE EFFECT OF HEIGHT OF SOIL ABOVE THE WATER TABLE ON OXYGEN DIFFUSION RATE PRE-EMERGENCE AND POST-EMERGENCE

Treatments	Grams of oxygen x $10^{-8}/cm^2$ per minute							
	1	2	3	4	5	6	7	8
Pre-Emergence								
June 28	26.3	23.9	17.7	35.9	58.6	69.5	85.3	56.9
July 2	35.3	28.1	30.7	33.2	67.3	93.4	79.3	65.3
Average	30.8	26.0	24.2	34.5	62.9	81.5	82.3	61.1
Post-Emergence								
July 9	25.8	26.0	30.7	29.5	64.9	103.8	110.5	67.6
July 16	11.2	9.3	12.8	19.6	40.1	76.2	61.7	33.5
July 23	7.4	6.1	9.1	14.2	49.0	58.1	47.1	26.5
Average	14.8	13.8	17.5	21.1	51.3	79.4	73.1	42.5

differences in the rate of oxygen movement between the two periods with a higher rate obtained in the pre-emergence period. In addition it was observed that the differences between periods were of greater magnitude in the short columns than in the higher columns. For example, the average diffusion rate in the soils of Treatment No. 1 (the shortest column) were reduced from 30.8×10^{-8} grams per cm^2 per minute to 14.8×10^{-8} grams per cm^2 per minute, the difference being 16.0×10^{-8} grams per cm^2. The diffusion values for Treatment No. 6 (an intermediate height column) dropped only 2.1×10^{-8} grams per cm^2 per minute from the pre-emergence to the post-emergence period. The moisture content in Treatment 1 was 25.4 percent while that of Treatment 6 was 16.1 percent, (Table 1). The greater decrease in the shorter and wetter columns is thought due to the reduction in effective pore space because of settling and consolidation of particles and because of an increase in oxygen consumption due to multiplication of micro-organisms within the soils. Under the conditions of heat and moisture the rapid reduction of organic matter would also have a significant effect on soil conditions.

The number of days from planting to emergence are presented in Table 3. In Treatments 1 to 4 only two of the 32 sets grew and of these only one made any appreciable amount of growth. Because of the very poor growth obtained a crop failure is recorded in this group of treatments. It is indicated that the condition of the soils in Treatments 1 to 4 inclusive was entirely unfavorable to the maintenance of life processes in potato sets.

Satisfactory rates of sprouting and plant development were obtained for the sets planted in the soils of Treatments 5 to 8 in which the calculated emergence was 90 percent of the sets planted. The most rapid rate of emergence was obtained in the soils of Treatment No. 5 for which the average emergence rate was 11.3 days as compared with 12.9, 11.9, and 14.4 days for Treatments 6, 7, and 8 respectively. In the case of Treatment 8 the longer average time required for emergence was probably due to the low amount of available moisture in the surface soil. Table 1 shows the moisture content of the surface soil in Treatment 8 was 6.8 percent which was less than one-half that measured in Treatment 5 for which the most rapid emergence rate was recorded.

In connection with the failure of growth in pots it should be mentioned that during the pre-emergence period a glazed (slick) appearance was noticed on the soil surface in most of those pots where plants did not emerge. An examination of the sets following the two week pre-emergence interval revealed that they were completely decayed. Inadequate rate of oxygen supply is suggested as the reason why the sets failed to grow. The opinion is in agreement with ideas put forth by a number of workers (4, 7, 24, 33, 55) all of whom concluded that the residues of metabolism under limited oxygen supply act as poisons capable of disrupting the normal process on which the life of cells depends.

The average growth rates for the individual plants in Treatments 5 to 8 are presented in Table 4. The plants in Treatment No. 5 made the most rapid growth with an average increase of 1.47 centimeters per day,

TABLE 3

THE EFFECT OF HEIGHT OF SOIL COLUMN ABOVE WATER TABLE ON THE TIME REQUIRED FOR POTATOE SETS TO EMERGE

Treatment	Number of days after planting							
	1	2	3	4	5	6	7	8
Replicate 1	x	x	x	x	8	12	x	15
2	x	x	x	13	8	x	10	17
3	x	x	x	x	12	12	12	15
4	x	x	x	x	x	12	15	19
5	x	8	x	x	15	10	15	15
6	x	x	x	8	11	10	10	11
7	x	x	x	x	13	17	10	13
8	x	x	x	x	12	17	11	10
Average days					11.3	12.9	11.9	14.4

x No emergence because of set decay.

TABLE 4

THE EFFECT OF HEIGHT OF SOIL COLUMN ABOVE WATER TABLE ON THE RATE OF GROWTH OF POTATO PLANTS

Treatment	Height in Centimeters			
	5	6	7	8
Date				
July 13	9.6	7.1	9.4	6.4
15	12.7	9.3	10.8	9.0
17	15.0	11.8	11.5	12.3
19	17.9	14.1	15.5	14.5
21	21.3	16.4	17.9	17.1
23	24.9	19.1	20.2	20.2
26	29.3	23.2	23.9	23.1
28	31.6	25.4	25.9	24.9
Average per day	1.47	1.22	1.10	1.23

while in Treatments 6 and 8 the daily height increases were 1.22 and 1.23 centimeters respectively. Plants included in Treatment No. 7 with an increase of 1.10 centimeters per day made the slowest growth in the experiment.

The data recorded in Table 5 present the numbers of stems on each plant and the total dry weight of each plant. There was considerable variation in the numbers of stems per plant as well as in the total weight of stems produced by each plant. For example, the yield of replicate 2 in Treatment No. 5 was 9.60 grams while only 0.52 grams was obtained in replicate 7 in the same treatment group. In the case of Treatment 6 the variation in yield was also very wide with the yield of the heaviest plant being 7.34 grams and the lightest 0.90 grams of dry matter. The variations within Treatments 7 and 8 are somewhat less extreme than those obtained in the other treatments. Statistical analysis of the data indicated no significant difference between the treatments in the test. The value obtained for the standard error serves to point out the fact that there is as much variation within as between the treatments.

With the idea of bringing the individual plant values to a more uniform basis for comparison of the total growth the average weight of each stem was determined. The average weights for individual stems are presented in Table 6. The values obtained continue to indicate the uneven pattern of growth as pointed out in the discussion of Table 5. The general trend, however, is to a heavier growth of Treatment 5 in which an average weight of 2.00 grams per stem was recorded as compared with 1.23

TABLE 5

THE EFFECT OF HEIGHT OF SOIL COLUMN ON THE NUMBER STEMS AND YIELD PER PLANT

Treatment	Number of Stems and Yield per Plant							
	5		6		7		8	
	Stems	Weight	Stems	Weight	Stems	Weight	Stems	Weight
Replications	no.	gm.	no.	gm.	no.	gm.	no.	gm.
1	2	1.28	5	7.34	-	-	2	1.52
2	4	9.60	-	-	1	1.48	3	1.61
3	3	4.40	3	3.35	2	3.25	5	3.04
4	-	-	2	6.00	1	1.20	2	0.48
5	1	2.13	2	1.46	1	1.06	5	3.46
6	2	8.64	2	1.60	5	6.89	1	3.60
7	1	0.52	2	1.15	4	3.94	1	0.75
8	1	2.50	1	0.90	3	2.03	1	2.48
Average		4.15		3.11		2.98		2.12

Analysis of Variance: Table 5

	D.F.	S.S.	M.Sq.	F
Total	31	195.1060		
Replications	3	39.4870	13.162	1.90
Treatments	7	10.0278	1.433	0.21
Error	21	145.5912	6.933	

TABLE 6

THE EFFECT OF HEIGHT OF SOIL COLUMN ON THE YIELD PER STEM

Treatment	Weight per Stem			
	5	6	7	8
Replication	gm.	gm.	gm.	gm.
1	0.64	1.47	-	0.76
2	2.40	-	1.48	0.54
3	1.47	1.12	1.63	0.61
4	-	3.00	1.20	0.24
5	2.13	0.73	1.06	0.69
6	4.32	0.80	1.38	3.60
7	0.52	0.58	0.99	0.75
8	2.50	0.90	0.68	2.48
Average	2.00	1.23	1.20	1.21

Analysis of Variance: Table 6

	D.F.	S.S.	M.Sq.	F	F .05
Total	31	33.3015			
Replications	3	9.6053	3.202	3.177	3.07
Treatment	7	2.5367	0.362		
Error	21	21.1595	1.008		

grams for Treatment 6. In Treatments 7 and 8 the average weight per stem is 1.20 and 1.21 grams respectively. Statistical analysis of this modified comparison once again has shown there is no significant difference between the treatment means. Comparing the analysis with that of Table 5 the most obvious difference is the smaller error variance here, showing that a variation between replications is responsible for a large part of the total dispersion. Because of this wide variation between replicates it seems appropriate that a suggestion be offered as to causes contributing to this variation. The variable soil condition because of freshly packed soil columns no doubt contributed considerably to the variation and probably was responsible for an uneven moisture distribution, particularly in the higher columns. In trials where dependence is placed on capillary rise in the soil columns it would seem the most uniform condition would be obtained if undisturbed cores were obtained directly from the field. If this plan were not feasible the next best would be to prepare the pots considerably in advance of the time they were to be used thereby providing opportunity for consolidation of the packed material and possibly a development of more uniform conditions within the soils of each pot.

Table 7 presents a summary of data and affords an opportunity for comparison of the various factors which were measured or observed during this trial.

The results have pointed to the essential nature of soil oxygen and the harmful effects which may occur when this material is in minimum supply. It is indicated that unfavorable growth conditions existed in

TABLE 7

SUMMARY OF DATA ON SOIL MEASUREMENTS AND YIELDS

Treatment number	Soil height	Surface of Soils		Average yield	Oxygen diffusion rate gm. x 10^{-8}/cm.^{2}/min.	
		Porosity	Moisture			
	inches	%	%	grams	P.E.	p.e.
1	2	2.4	25.4	0	30.8	14.8
2	4	4.8	23.8	0	26.0	13.8
3	6	7.1	22.4	0	24.2	17.5
4	8	9.1	21.0	0	34.5	21.1
5	10	12.2	19.0	4.15	62.9	51.4
6	14	16.7	16.1	3.11	81.5	79.4
7	18	20.7	13.0	2.98	82.3	73.1
8	22	22.9	12.0	2.12	61.1	42.5

Treatments 1 to 4 inclusive while in Treatments 5 to 8 growth was obtained when the soil water reactions were improved. By changing the height of soil columns the porosity was increased from 9.1 percent (Treatment 4) to 12.2 percent (Treatment 5) and the oxygen movement increased from 34.5×10^{-8} to 62.9×10^{-8} grams per square centimeters per minute which provided conditions favorable to the life and growth of the potato sets.

The findings of this trial are in accord with results reported by Cannon (16) who found that maize seedlings would not grow when soil oxygen was less than 3 percent while optimum growth was obtained in his experiment when oxygen content had been increased to 8 percent of soil volume. Baver and Farnsworth (3) have also pointed out the essential nature of soil aeration to crop growth and in their tests a total air capacity of 8 percent gave good stands of sugar beet but when air capacity fell to 2 percent about half the beets perished and yields declined.

Figure 6 shows the relation between the various observations as listed in Table 7. It is shown in Figure 6 that decreases in soil water content were accompanied by increases in non-capillary porosity. For example, reductions in soil water from 25 to 12 percent were accompanied by increases in non-capillary porosity (air space) from 2.4 to 23.0 percent. The oxygen diffusion rate increased with the increases in porosity until a point was reached at which the instrument was incapable of functioning efficiently. Then a decrease in reading was observed. In this trial the decrease was noted at about 20 percent porosity and 14

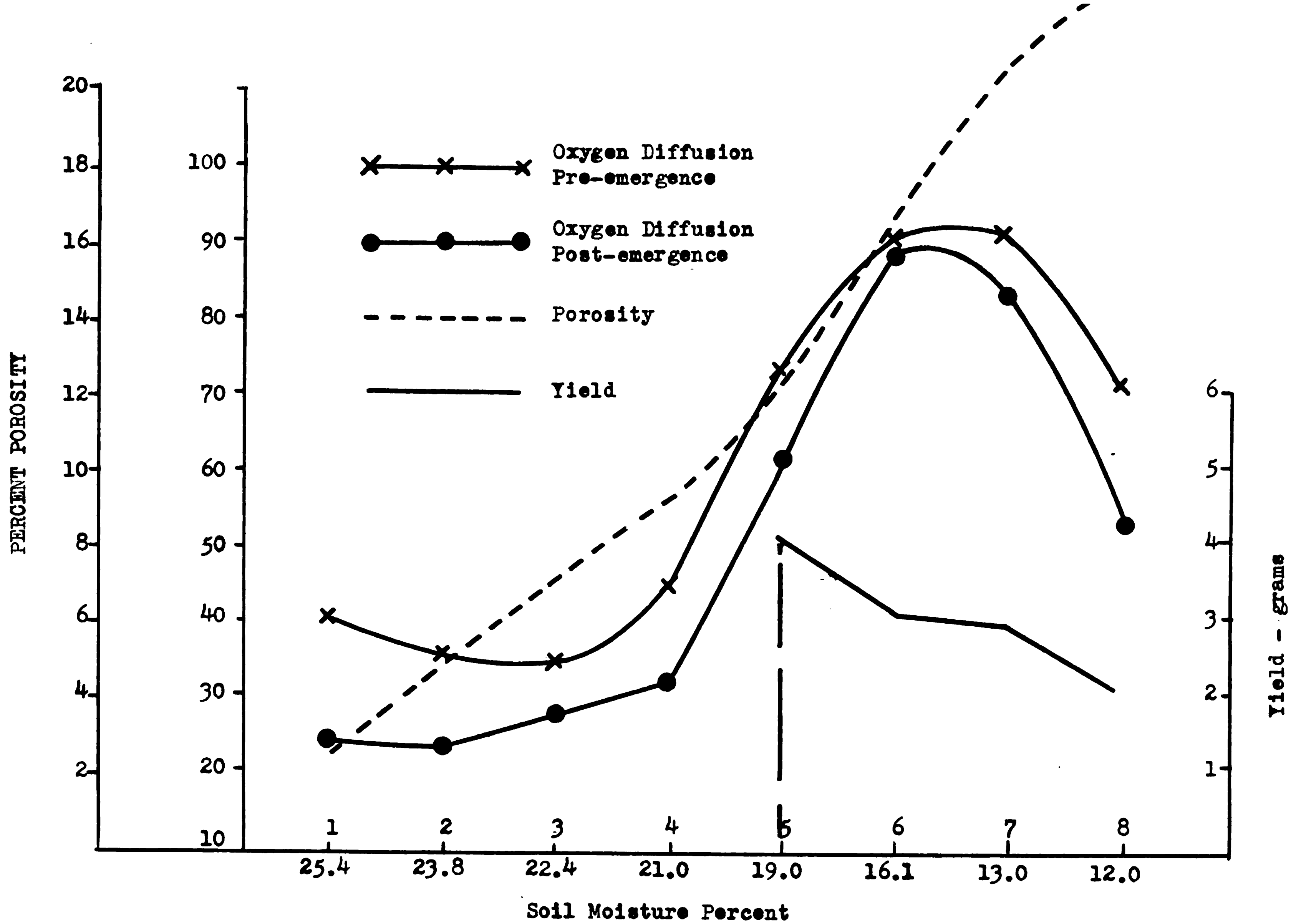


Fig. 6. Comparative Data on Soil Measurements and Yield

percent soil moisture. It is believed that at this soil water content there was insufficient moisture in the soil to adequately moisten the surface of the electrode and allow for optimum operation of the instrument. Lemon and Erickson (41), and Van Doren (58) explained that the effectiveness of the platinum electrode is dependent upon a complete moisture film on the exposed electrode surface. The lack of this moisture film causes errors in the observed values. They have pointed out that under these conditions a measure of oxygen diffusion is meaningless because soil porosity and aeration are improved and are no longer a limiting factor to plant growth.

In Figure 6 the diminishing yield values are believed related to the lower moisture content of the soils as the height of soil column increased from 10 inches for Treatment 5 to 22 inches for Treatment 8.

B. Temperature Experiment

The data in Table 8 show that when submerged for only one day sets retained a natural appearance and the tissue was firm and quite normal regardless of temperature. There was a slight indication of sprout growth taking place. In two days the sets submerged at 50°F and 60°F retained a normal appearance but those held at a temperature of 70°F and above seemed to have some softening of the tissue on the cut surfaces. On the third and successive days a softness or sponginess of the tissues was quite noticeable in all except those held at 50°F temperature. In the 50° treatment the tissue of the sets appeared to be not greatly affected by the unusual conditions of the six day test.

TABLE 8

RESULTS OF SUBMERGING AND HOLDING POTATO SETS IN SATURATED SOIL AT FOUR TEMPERATURES FOR PERIODS OF FROM ONE TO SIX DAYS DURATION. CONDITIONS IMMEDIATELY ON REMOVAL FROM SUBMERGENCE, AND RESULT OF GREEN SPROUTING ONE WEEK LATER

Days ubmerged	Temperature F°							
	50°		65°		70°		85° - 105°	
	On removal	1 week later	On removal	1 week later	On removal	1 week later	On removal	1 week later
1	F	S	F	S	F	S	F	D
2	F	S	F	D	Sp	D	Sp	D
3	F	S	Sp	D	Sp	D	Sp	D
4	F	D	Sp	D	Sp	D	Sp	D
5	F	D	Sp	D	Sp	D	Sp	D
6	F	D	Sp	D	Sp	D	Sp	D

F = Firm　　Sp = Spongy
S = Sprouting　　D = Decay

The observations in the green-sprouting test were made one week after each lot of sets had been placed on the trays. These results are also set out in Table 8. The tubers submerged for one and two days at 50°F were alive and grew sprouts. They seemed to be relatively unaffected by the period of confinement under water. Those tubers submerged for three days at the 50° temperature also developed a good sprout but typical blackheart symptoms such as contraction and discoloration of tissue in the center of the tuber was observed. There was, however, enough firm and living tissue under the skin to permit sprouting. These tubers were not completely harmed and would doubtless make some growth if placed in soil but they could not be classed as good material for seed purposes. The tubers submerged for periods longer than three days at the 50° temperature did not grow in the sprouting test but were in an advanced stage of decay after the end of one week, Table 8.

The sets submerged for one day at 65oF and 70oF were still alive as indicated by growth in the sprouting test. Those submerged at these two temperatures for periods of two days or longer failed to sprout when placed on the trays and were in an advanced stage of decay at the end of one week, Table 8.

There was no indication that tubers submerged at the greenhouse temperature (85°F or above) were alive after being immersed for only one day. Extensive tuber damage was easily observed in all sets held at this temperature and no growth was obtained when the sets were placed on the trays.

Further evidence of the comparative damage to potato sets when submerged in saturated soils at various temperatures is illustrated on Plate 4. The sets in Figure 7 are typical of those which had been submerged for five days and putrefactive decay had taken over in all pieces. Somewhat less damage is indicated in Figure 8, the specimens having been submerged at the indicated temperatures for only two days. At 50°F no serious tissue injury was observed and sprouts grew in a normal manner. The sets from the other temperatures were not living and the tissues were considerably contracted as observed when blackheart is present, and decay is active.

The possibility of using blackheart potatoes for seed purposes has been investigated by Coons (21). He found affected tubers undesirable for seed purposes, even though only partly damaged by the disease and reported that germination, vigor, and yield under field conditions were inversely proportional to the degree of blackheart developed in the seed piece. Heald (33) stated that potatoes affected by blackheart sprout feebly, or not at all, and are unfit for seed purposes but it is possible that slightly affected tubers may be strong enough to make a good seed.

The findings of this test agree very well with those reported by other workers. Potato sets kept at 50°F or below may not be greatly affected by short periods of anoxia caused by unusual soil conditions such as flooding but serious physiological dissorders occur at temperatures of 60°F or greater when air (oxygen) supply is reduced if only for a brief time as in the case of soil flooding.

PLATE 4

SPECIMENS FROM THE SOIL FLOODING AND GREENSPROUTING TEST

Fig. 8

Sets submerged two days at four temperatures then held one week in the greensprouting test.

Very slight decay shown on sets submerged at 50°F and sets had begun to sprout.

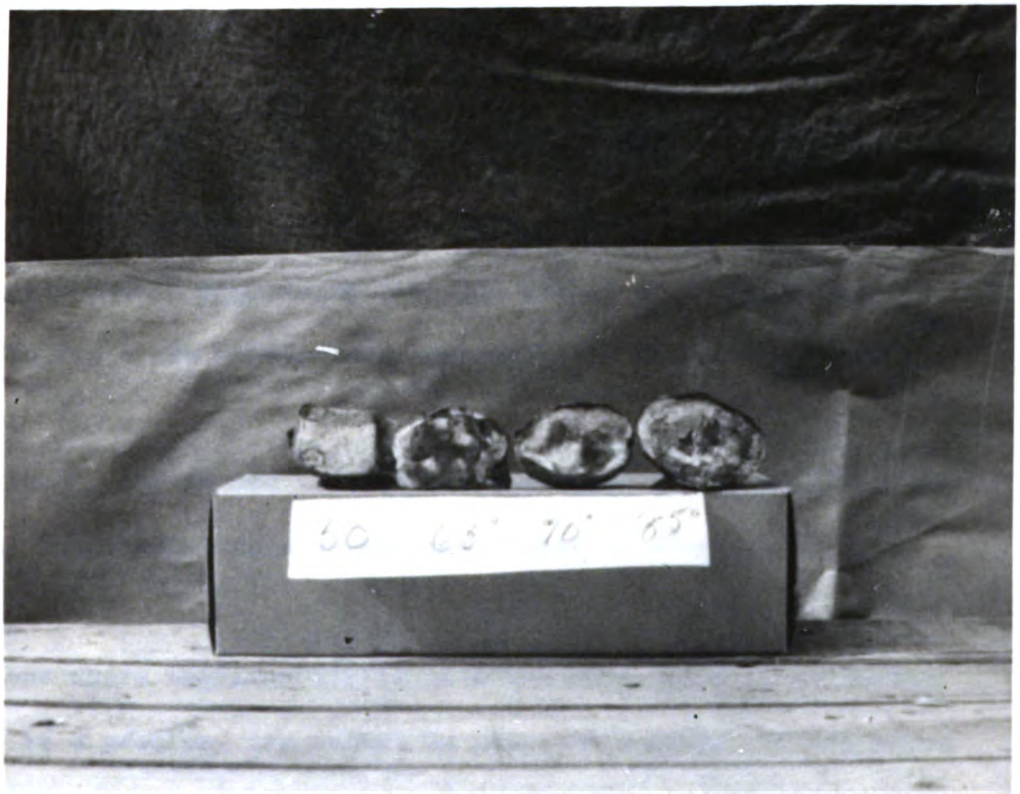
At temperatures of 60°F and higher all specimens were rotting and had no sprouts.

Fig. 7

Sets submerged five days at four temperatures and held one week in the greensprouting test.

Soft rots have invaded all the specimens and no sprouts were visible indicating complete suffocation of the sets.


50° 65° 70° 85°


50 65° 70° 85°

V. SUMMARY

Oshtemo sand in eight different heights of soil columns was provided with constant level sub-irrigation as a source of capillary water supply. Depth to water level developed variations of water content and air pore space. The related effects of soil water and soil aeration on the germination and growth of potato sets planted in the soil were studied.

1. Differences in vegetative growth were obtained and the close relationship between soil air supply and the health of potato sets was demonstrated.

2. Increases in soil moisture above 19 percent reduced soil air supply to a critical level at which death and decay of practically all sets was observed.

3. In an immersion test potato sets were held in soil under water for periods from one to six days and at various temperatures. The results obtained suggest that in appraising possible damage due to prolonged flooding in the field the temperature appears to be a very important consideration.

4. Non-capillary porosity and soil moisture content of the seed bed are very important factors in the starting and growth of strong healthy potato crops.

5. In locations where infiltration is slow and water ponding or excess soil moisture is a problem, the effect on potatoes because of the accompanying reduction in soil aeration is doubtless a limiting factor in successful potato growth.

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