Technical Bulletin 144 June 1940

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Accepted for Publication June 19, 1940

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A Laboratory Study of the Drainage Requirements of Sweet Clover[1]

P. W. MANSON

THE PROBLEM of drainage in agriculture is important enough in the United States to justify lifting the design of farm drainage from the realm of practice based almost wholly on experience to that of a science. About one sixth of our farm land would be affected by improved drainage practices, and the study of the relationship of soil moisture to crop production is sufficiently important to make more scientific study desirable and advantageous. This scientific approach has not yet become common, and attempts to make it so have thus far been wholly neglected from the plant factor side.

The problem of drainage design as influenced by soil type has largely been solved. The problem still before us is the scientific determination of the rate at which drainage of saturated soils must take place and the depth to which the water table must be lowered for the various types of crops to get optimum results in quantity and quality of yield.

Since a close relationship exists between root development and crop production, proper precautions must be taken to insure a vigorous root system. In the case of most crops, a vigorous plant cannot be grown where there is an excess of water in the soil.

A shallow water table limits the depth to which plant roots will penetrate the soil because the roots of upland plants will not penetrate free water. Many marsh plants can thrive on wet soil conditions, but seldom will even their root systems develop to any great extent below the surface of the ground water table. This inability of plant roots, generally, to penetrate waterlogged soils is reflected in low quality and low quantity crop yields.

A well-drained soil will make possible the deep and wide root penetration necessary for vigorous growth and heavy yields. A shallow rooted system may produce a normal top growth, but usually the ground water recedes much more rapidly than the

[1] A master's thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Agricultural Engineer, June 1940.

roots can follow. As a result there is frequently serious injury to the plants from lack of moisture because a high water table early in the season prematurely arrested development. The rise of the water table into the zone of roots already matured will injure and often kill those roots exposed to stagnant saturation for any appreciable length of time. Some plants thus succumb to excessive ground water much more quickly than others. However, most plants will withstand a waterlogged condition of the soil more successfully and for a longer period if the free water is not stagnant but is being drawn off by subdrainage at an appreciable rate.

In spite of general recognition by the agriculturally minded of the need and advantages of drainage, its practice is not yet on a scientific foundation. Modern knowledge of hydrology, hydraulics, and soil physics has made possible scientific design of drainage systems that will remove the excess water from the soil at any desired rate. Just what this desirable rate of removal of excess water from the soil should be to prevent injury to any one of the many different crops is not known, and, so far as the author is able to discover, little scientific research has been conducted on the problem.

THE PROBLEM

The purpose of this study has been to determine the optimum soil moisture requirements of a given crop, especially in those areas in need of subdrainage, and the minimum rate at which the removal of a saturated condition of the soil must be accomplished to obviate serious injury to the crop. Effective study of the problem first of all necessitated design of a scientifically reliable method and indoor physical set-up, which is described later in this discussion. It is hoped that, through this study, supplemented by similar studies to follow, it will be possible to determine the optimum soil moisture conditions for the growth and development of all major crops. This optimum condition would be obtained by the adaptation of known subdrainage methods.

The crop selected for this study was biennial white sweet clover. This particular selection was made because local conditions made it necessary to grow the crop almost wholly under artificial light, and sweet clover responds to artificial light more readily than most other local farm crops. However, the fact that sweet clover thrives better than most crop plants in excessively wet soils has greatly increased the difficulties of this particular study.

The Plant-Growth Soil-Moisture Relation—As a basis for our considerations, it seems desirable to review briefly certain pertinent principles of the plant-growth soil-moisture relation.

An average silt loam soil has a total pore space of about 50 per cent. When this soil is well-drained, 50 to 75 per cent of the pore space is filled with capillary water leaving 25 per cent or more of it for the free circulation of gases. It is the abundance of carbon dioxide and other gases in the air passages useful to plants that, in a large measure, makes possible, through the agency of capillary moisture, soil organisms, and the root structure, the preparation and assimilation of mineral nutrients.

Only the capillary water of the soil can be used by the plants. Neither that capillary water nor the necessary gases are available when free water occupies the pores of the root zone. In almost any soil waterlogged conditions will tend to occur at times, and the only way to obviate injury from them is to provide for prompt removal of the free water from the soil. The principal question that arises is at what minimum rate must such removal occur, economically to protect a given type of plant from serious injury. That question is the problem involved in this study.

WORK OF OTHER INVESTIGATORS

The literature of drainage contributes little to the problem. Some investigators have offered general recommendations relative to the rapidity with which the excess water should be removed from the root zone to prevent plant injury, but the author is unable to find any scientific data pertaining to the problem.

W. J. Schlick (6), in discussing the relation of capillary movement to underdrainage, states that for an average Iowa soil and for ordinary field crops the desirable depth of the water table is from 2.5 to 3 feet below the average elevation of the crop roots. If the water is held at too low a stage, an insufficient amount of moisture will be raised to the upper soil layers and the crops may suffer.

The effectiveness of a drainage system is indicated by the distance from the ground surface to the water table. J. Rothe (5) suggests for this critical distance not less than 50 centimeters (about 20 inches) for cultivated crops and 40 centimeters (about 16 inches) for grass crops, but his conclusions are drawn wholly from laboratory studies of spacing and depths made only with sands, which fact limits their applicability.

B. A. Etcheverry (3), from recommendations and miscellaneous observations, makes the following deductions in tabular form:

"Desirable Minimum Depth to the Highest Point of the Mean Water Table in Inches"

	Sandy soils and relatively warm dry climates	Medium soils and rainfalls fairly well distributed	Clay loams and rainfalls well distributed
	inches	inches	inches
Meadows and pastures	12	20	24
Ordinary cultivated field crops	24	32	36-40
Deep rooted crops and orchards	30-36	40-50	48-60

In 1934 J. H. Neal (4), in discussing the proper spacing and depth of tile drains, writes as follows:

"The writer has observed that crops will not be injured if the water table at the mid-point is kept one foot or more below the surface at all times, and two feet or more below the surface 75 per cent of the time. Even though the water comes within one foot of the surface, but not over the surface, the injury will not be great for most crops if it can be lowered again in a few hours. The grass crops are much more tolerant of water than the ordinary row crops. As a rule, the truck crops are the most sensitive to excess water and, therefore, should have the most effective drainage system.

"The limiting conditions of this study beyond the writer's control have not permitted a close scientific study of plant development in relation to excess free water in the soil so that this phase of the problem of tile drainage design is considered outside the scope of this discussion."

It is obvious, from the literature cited, that little or no scientific research has been conducted to determine the tolerance of the many different farm plants to waterlogged conditions. To date statements relative to this field are limited to general, personal observations. The investigation herein started must be completed for all major crops before the drainage engineer can scientifically design a drainage system.

THE PHYSICAL SET-UP AND EXPERIMENTAL PLAN

The Experimental Soils—During the fall of 1936, four blocks of undisturbed field soil were brought to the Agricultural Engineering laboratories at University Farm, St. Paul, from the same tract on which J. H. Neal made his studies on tile spacing and depth near Meadowlands, Minnesota. These blocks were secured in an undisturbed state in the following manner: Four square bottomless zinc lined boxes of wood, 33 inches on a side and 36 inches deep (inside dimensions), were built and bottoms of the same construction were made and held in readiness. The blocks of soil were trenched around in the open field carefully so as not to crack them or otherwise disturb their continuity and of such a size that the bottomless boxes could be forced down over them with a tight fit. Then by means of a screw jack and a sheet of boiler plate the soil blocks were carefully sheared off below the boxes and, by means of a tripod and block and tackle, were raised to the surface; the top protected by a temporary cover, the box rolled over bottom up; and the regular bottom securely fastened on in place of the boiler plate. The boxes were then loaded and brought by truck to University Farm and installed and equipped in our laboratories where the studies were made. In order to insure, as nearly as possible, exact similarity in the soil of the four boxes, the soil blocks were taken exactly adjacent to each other as shown in figure 1.

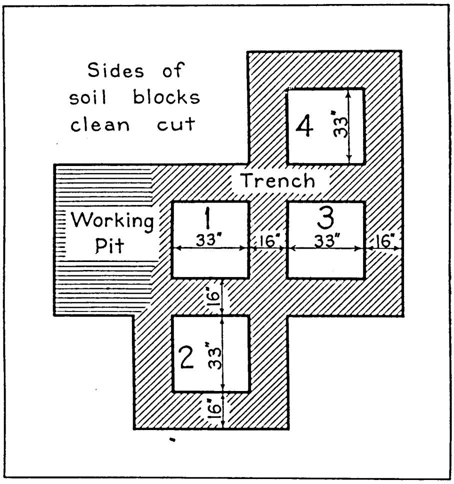


Fig. 1. Relative Location of Soil Blocks as Removed from the Field

Before the water-control system was set up, the front on each box was removed; small sample cubes for determination of maximum water holding capacity of the soils were taken out; and then the sides were put back, sealed watertight with plastic asphalt roofing cement. A heavy extra strength plate glass window 6 inches wide was installed in each front side for constant observation of root

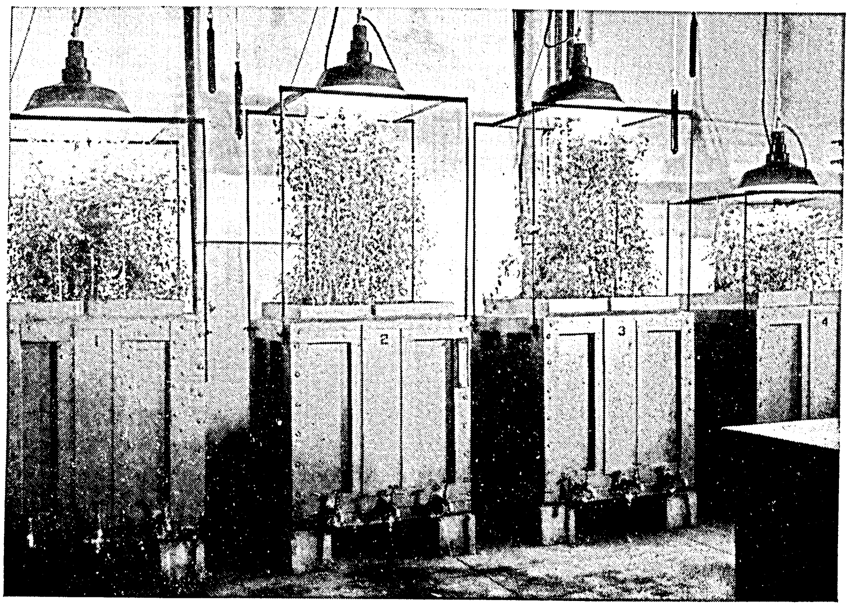


Fig. 2. General View of the Laboratory Set-up

development from the outside should such observation prove desirable. However, this arrangement was not effective, and these windows were finally covered as shown in figure 2.

Control of drainage, water level, and light was then secured in the following manner as shown in figures 3 and 4.

Drainage—As a substitute for drainage, three brass pipes were placed through the soil at the bottom of each box. These brass pipes were ¾ inch in outer diameter with inner end closed and sides perforated along all four quarters with holes one twenty-fifth inch in diameter spaced at 2-inch intervals for the entire length of each pipe—the holes being staggered on the different lines. The water could also be forced back through the perforations into the soil to raise the water table. These pipes were extended through the front faces of the box and connected to the rest of the water control works. Gate valves were installed on the outer end of each pipe to permit individual control and more rapid discharge in case such control should become necessary.

It will be noted from figure 3 that the stand pipe fastened to the back of the box and the horizontal drain pipes in the interior of the box are connected. Under these hydraulic conditions, the water in the box will seek the same level as that in the stand pipe. The head of water in the stand pipe can be adjusted to any level by raising or lowering the rubber overflow tube to the desired height. By such arrangement, the water table can easily be controlled to ⅛-inch variation. When the head in the stand pipe is varied by an inch or more, it takes the water table in the box several hours to adjust itself to the same elevation. The water that is transpired or evaporated from the box does not alter the ground water elevation because the water that is so removed is replaced by an equal amount from the stand pipe, thus always maintaining the same water elevation inside the box as in the stand pipe.

A drip method was devised for lowering the water table at a uniform rate. By this method the drain water leaves the stand pipe through a piece of capillary glass tubing 1 inch in length and 0.009 inch in diameter. The discharge through this capillary tube can be calibrated by varying the head to deliver different flows.

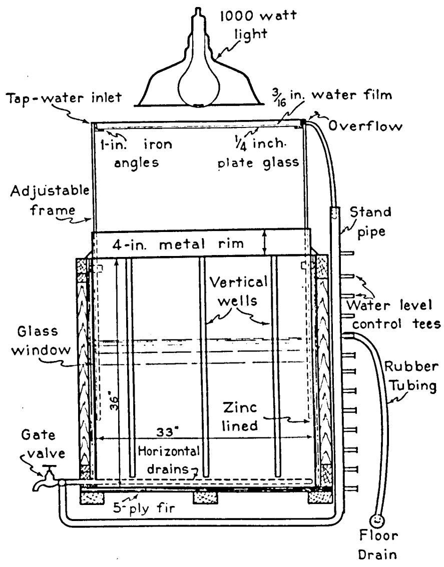


Fig. 3. Side Elevation Showing the Essentials of One Box for Controlling the Drainage, Water Table, and Lighting

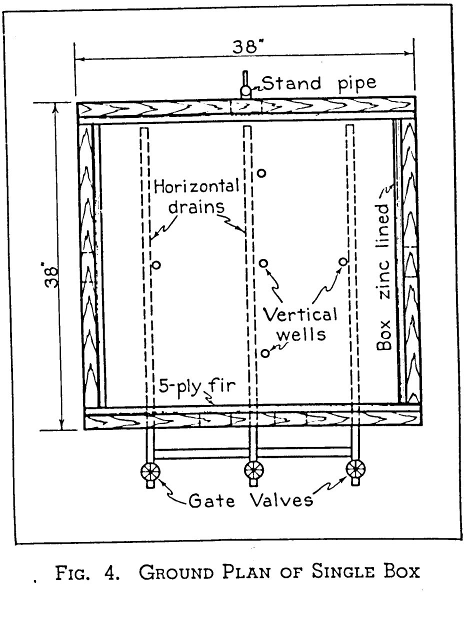


Fig. 4. Ground Plan of Single Box

The height of the water in the boxes is checked by measurements in the five vertical wells, located as shown in figures 3 and 4. The water table may also be observed through the glass window installed in front of each box, originally intended for observing the root development.

LIGHT

Preliminary Set-up—The windows in the laboratory are located on the west and north walls. Because the soil boxes were placed along the west wall, the west windows were covered to reduce any interference from outside light. The shades on the north windows were not drawn. A 500 watt light bulb was placed in a 14-inch metal dome reflector suspended from the ceiling over the center of each box. By a pulley and weight arrangement, the lights could be adjusted to any height up to 6 feet above the boxes. For the preliminary tests the light was on for 12 hours each day and adjusted to different heights above the boxes up to 48 inches.

Early Problems Encountered—On February 27, 1939, 225 sweet clover seeds were planted 2 inches apart each way in each box. The water table was set at 6 inches, and the surface sprinkled after seeding. The 500 watt bulb, then turned on, produced enough heat when placed 42 inches above the box to cause drying and checking of the surface soil. Two laboratory made humidifiers were installed in the same room to see if the drying of the surface soil could be checked by increasing the humidity. The two humidifiers raised the humidity from 26 to 50 per cent. This extra moisture did improve the surface conditions somewhat but was objectionable because it left a wet film over all the equipment in the laboratory.

Four days after seeding the first plants appeared. On the eighth day 47 per cent of the seeds planted had sprouted. After 11 days many of the plants were several inches high but were of a very inferior quality. The stems were thin and weak, the color light green, and within two weeks after planting most of the plants had "damp killed." This was the result of too much moisture accompanied by too high a temperature at the surface of the soil.

Under the circumstances it was deemed advisable to transplant to the boxes 3- to 4-week-old seedlings started in a greenhouse. Hence on May 8 sweet clover seedlings, 2 to 6 inches high, were planted 4 inches apart each way in each box. The light bulb was brought within 20 inches of the ground surface to see if the increased light intensity would not benefit the plants. (Light intensity at any point varies as the square of the distance of the light from that point; hence, by reducing the distance from light to object one half, the intensity is increased approximately four times.)

After 12 days the seedlings had reached a height ranging from 10 to 20 inches, but they were not vigorous. None of the seedlings "damp killed," but in trying to seek more light, the plants developed long, thin stems. These weak plants were cut back to 2 inches and the light left at 20 inches to see if a stronger stem would not mature. Cutting back of the plants did not help much. After 18 days some of the plants cut back again reached a height of 21 inches, but they still were extremely weak. These plants were then cut back to 4 inches and the lights left on for 18 hours a day instead of 12 as previously. By July 1 it was obvious, from the weak growth again resulting, that to grow vigorous plants in the laboratory some improvement must be made in the control of the artificial light.

Final Set-up—The early investigations had proven conclusively that to produce plants comparable to normal outside growth it was essential that there should be more light and less heat.

A search was made of all available literature pertaining to the subject in the hope that some information might be found that would help in the design of a cooling system. A. N. Wich (7) and A. J. Beber (1), working under Dr. Elmer S. Miller of the Botany Department of the University of Minnesota on the effect upon plant growth of light from which the infra-red rays had been removed by water filters, state that their studies showed that little or no light necessary for good plant development is removed by light filters of water, 2.5 centimeters or less in thickness.

When radiation falls on a dark object the surface becomes warm, showing that much of the radiant energy has been absorbed and converted into heat. If the radiant energy strikes a highly polished surface, the temperature change of the surface will be small because most of the radiant energy is reflected instead of being absorbed. Green foliage has a high absorptive power for radiant energy, making it extremely hard for plants to combat the heat energy that is being released by the artificial lights. This is undoubtedly one reason why the sweet clover would not thrive under the artificial light as it was applied at first.

Water is transparent but only slightly diathermanous, while glass is both transparent and highly diathermanous to radiation from hot bodies. It seemed a reasonable possibility, therefore, that some sort of thin water filter placed between the bulb and the plants might solve the lighting problem by intercepting most of the heat without seriously interfering with the passage of light.

The Design of the Heat Filter—A heat filter was designed as follows (figs. 2, 3, and 14): Strips of 1-inch angle iron welded together form a hollow square frame that supports a plate of glass, 32 inches square and ¼ inch thick, which in turn constitutes the support of the water film. The glass is set snugly on the angle iron frame and sealed watertight with asphalt mastic. The angle iron frame is welded to four vertical steel rods ½ inch in diameter which in turn are fastened to the box by thumb screw clamps that permit the filter to be set at any distance above the soil surface up to 4 feet.

Tap water, constituting the heat filter, at a temperature of about 56° F. flows onto the glass through a small tube at the front of the frame and drains off at the back at a temperature of about 77° F. The outlet is set sufficiently high to maintain, over the glass, a layer of water whose thickness does not exceed 3/16 inch. The rate of flow of water over the glass varies slightly but will average about 5 to 5½ gallons per hour. The overflow water empties into the stand pipe where some of it helps to maintain the desired head while the rest overflows into the floor drain.

The cooling system, just described, enables the use of any size bulb in the reflector without burning the plants. When this fact became evident, the light bulb was changed from a 500 watt to a 1000 watt bulb which was placed in the 18-inch bowl reflector for better light intensity and distribution.

Once every 3 or 4 weeks the plate glass must be cleaned to remove the dust sediment. This takes about 10 minutes per filter. Light intensity readings by a Weston photromic foot-

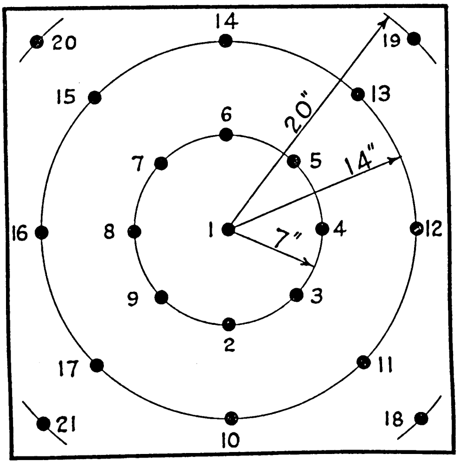


FIG. 5. LOCATION OF LIGHT INTENSITY READINGS

candle meter, before and after cleaning, show a maximum decrease of not over 6 per cent in light intensity due to dirt.

The tap water sometimes carries a sediment of rust and fine sand that is objectionable when deposited on the glass. This objectionable sediment is removed by passing the water through a glass-wool water filter before it reaches the glass plate. This device enables the period between cleanings to be greatly extended.

Room Temperature—The temperature in the laboratory varied between 65° and 75° F. during the day and was usually about 60° F. during the night. It may have been better to maintain a lower temperature, but this was not feasible since other research work was being conducted in the same laboratory during the course of this study. On several nights, when the outside temperature dropped rapidly and the windows were slightly opened, the temperature did drop to a minimum of 45° F. A soil thermometer was placed in one corner of each box to note ground temperatures. However, with the water table as high as it was maintained in these tests, the soil temperatures had little significance as, at a depth of 3 inches below the surface, they were practically identical with the temperature of the soil water which remained practically constant at a point several degrees below the average room temperature.

Light Intensity—Before plant growth was undertaken light intensity readings were made at 21 locations over the surface of each box and for distances of 12, 18, 24, 30, and 36 inches from the light bulb. The different locations of the light meter are shown in figure 5. A special rack made it possible to place the meter in exactly these same positions for all sets of readings. The results of 1000 light intensity readings are given in table 1. It will be noted from this table that the greatest light concen-

Table 1. Light-Intensity Measurements in Foot-Candles over Surface of Soil Boxes. Each Value Is Average of 25 to 100 Readings

Location	Distance, bulb to light meter				
	12 in.	18 in.	24 in.	30 in.	36 in.
Center	2005	1334	769	483	344
7 inches from center	1432	928	604	449	333
14 inches from center	990	714	504	381	285
20 inches from center	665	532	415	327	258

tration is at the center of each box and that the lowest readings are at the corners. This difference is reflected in the plant growth, the best plants usually being found nearest the center of each box. At just what position of the light bulb optimum plant development for the entire box will take place, has not been determined.

Period of Exposure of Plants to Light—A trial run was made to determine how many hours each day the lights should be left on to produce the best growth. On September 18, seeds were planted in each of the four boxes, number one receiving 12 hours of light per day; number two, 14 hours; number three, 16 hours; and number four, 18 hours per day. After four weeks the growth was carefully checked and results recorded in table 2.

Even though the results shown in table 2 are based on only one run, it is quite evident that the proper exposure is 18 hours per day with the light 18 inches above the surface.

Table 2. Plant Development under Different Periods of Light Exposure

Exposure per day hours	Number of plants	Average height inches	Total weight (wet) grams	Root development
12	9	5	8	Very poor
14	17	6	17	Poor
16	25	9	79	Good
18	32	11	90	Very good

PHYSICAL CHARACTERISTICS AND CLASSIFICATION OF THE EXPERIMENTAL SOILS

J. H. Neal (4) describes these soils as follows: "The surface 6 inches of the Meadowlands soils is a brown, silty-clay loam, and the second 6 inches and the second and third feet are gray, silty loam containing less organic matter. Occasional clay layers appear in the second, third, and fourth feet."

Table 3. Physical Characteristics of the Soil as Related to Drainage* (Each Value Average of Two or More Tests)

Box No.	Depth of soil sample	Moisture equivalent	Lower plastic limit	Upper plastic limit	Plastic number	Total sand by hydrometer 40 secs.	Total colloidal content by hydrometer	Silt by hydrometer	Clay by hydrometer: Conventional clay 0.005-000 mm.	Clay by hydrometer: Finer clay 0.002-000 mm.	Box No.
	inches	per cent	per cent	per cent		per cent	per cent	per cent	per cent	per cent	
1	0- 6	35.6	27.4	43.1	18.7	15.8	60.0	42.5	41.7	33.5	1
1	6-12	26.4	17.8	34.8	17.0	14.4	65.1	41.3	44.3	37.3	1
1	12-24	28.5	18.0	29.4	11.4	14.5	67.1	34.6	50.9	44.3	1
1	24-36	24.8	19.0	24.5	5.5	29.1	55.9	33.7	37.2	30.0	1
1	Average	28.8	20.6	33.0	13.2	18.5	62.0	38.0	43.5	36.3	1
2	0- 6	28.1	21.2	35.8	14.6	14.0	64.8	38.2	47.8	38.6	2
2	6-12	25.2	16.5	29.5	13.0	16.7	57.4	45.8	37.5	28.7	2
2	12-24	32.4	22.9	38.9	16.0	10.6	77.1	26.8	62.6	53.6	2
2	24-36	20.0	15.6	18.9	3.3	42.4	42.6	29.3	28.3	22.8	2
2	Average	26.4	19.1	30.8	11.7	20.9	60.5	35.0	44.1	35.9	2
3	0- 6	27.2	20.5	33.5	13.0	14.7	63.8	42.2	43.1	34.8	3
3	6-12	25.1	17.9	26.8	8.9	12.5	62.4	46.3	41.2	32.9	3
3	12-24	39.5	26.7	40.7	14.0	8.9	84.3	17.9	73.2	60.0	3
3	24-36	24.8	21.2	24.3	3.1	29.7	51.1	36.3	34.0	26.5	3
3	Average	29.2	21.6	31.3	9.8	16.5	65.4	35.7	47.9	38.6	3
4	0- 6	26.7	19.3	33.9	14.6	14.7	64.1	38.2	47.1	37.5	4
4	6-12	25.6	17.4	27.2	9.8	18.4	52.3	46.6	35.0	29.4	4
4	12-24	37.3	25.8	41.5	15.7	11.3	80.0	19.9	68.9	60.4	4
4	24-36	19.9	16.3	19.8	3.5	51.4	40.3	20.5	28.1	22.8	4
4	Average	27.4	19.7	30.6	10.9	24.0	59.2	31.3	44.8	37.5	4

* On dry bases.

Table 4. Moisture Retained in Soil After Saturated Soil Is Allowed to Drain*

Depth of sample	Box 1	Box 2	Box 3	Box 4
inches	per cent†	per cent†	per cent†	per cent†
3	55.1	40.2	48.0	42.6
9	23.6	24.6	25.1	22.9
18	33.2	33.1	28.3	33.7
30	26.6	25.8	29.6	26.4
Average	34.6	30.9	32.8	31.4

* On dry basis.
† Each value average of two tests taken at locations as indicated in figure 6.

This soil has been classified by P. R. McMiller of the Division of Soils, University of Minnesota, as Swan silty clay loam. Samples of the soil immediately adjacent to each cube were collected in the field from the upper 6 inches, the second 6 inches, and the second and third foot. The physical characteristics of the soil of each box, as related to drainage, were determined in the laboratory from the samples secured and are shown in table 3.

The moisture equivalent in each case was determined by centrifuge as customarily used by the soil scientist.

The upper and lower plastic limits were determined by the method described by Neal (4).

The clay content and other related values were determined by the hydrometer method outlined by Bouyoucus (2).

The apparent maximum water-holding capacity of the soils at different depths was obtained as follows: Eight 2-inch cubes of soil were removed, as mentioned before and as shown in figure 6, from each of the 4 boxes by means of metal boxes, fitted with removable tops and bottoms. The bottomless boxes were forced into the main body of soil in each block and carefully extracted so that the samples would be undisturbed field soil. These samples were thoroughly soaked after which they were allowed to drain for 12 hours in a moist atmosphere by loosening the bottoms of the boxes. The moisture retained is recorded in table 4.

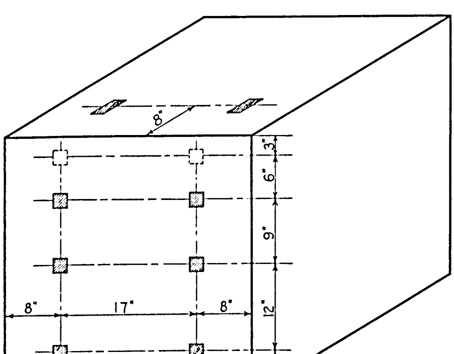


Fig. 6. Location at Which 2-Inch Cubes of Soil Were Removed from Each Box for Determining the Water Holding Capacity of the Soil

PREPARATION OF THE SOIL

It is evident from table 3 that there is some difference in the physical characteristics of the soil in the four boxes. Best to reconcile this difference, the upper 2 inches of soil was removed from each box, all mixed together, and sterilized. After sterilizing, the soil was again mixed and, by quartering, the same amount of soil was returned to each box. To this top 2 inches in each box was then added an equal amount of fertilizer at the rate per acre of 4300 pounds of limestone, 230 pounds of triple superphosphate, and 460 pounds muriate of potash.

WATER TABLE AND CROP MANIPULATIONS AND RESULTS

Sweet clover is more resistant to excessive soil water than most plants. In fact it is almost a marsh plant growing well under wet conditions. Consequently, the injurious results obtained by exposing this hardy crop to a waterlogged environment will not be as pronounced as they would probably be for the less water-tolerant crops. It should be remembered, however, that if the apparatus and procedure herein discussed will expose any marked differences in plant development for sweet clover, then the method will work to a better advantage for other crops less tolerant to excess soil water.

High Water Table Manipulations and Results—On October 12, 1939 seeds were planted in the four laboratory boxes and in four flats placed in the greenhouse. The greenhouse seedlings were to be held in reserve in case the laboratory plants "damp killed" or failed to mature properly. The laboratory plants did so well that there was no need for the greenhouse seedlings.

During the first five weeks after seeding, the water table in each box was set 9 inches below the surface after which it was adjusted to bring about different saturated conditions which are discussed in the following:

After the five weeks the seedlings in Boxes 3 and 4 were the most comparable and were used in the first test.

On November 16 the ground water table was brought to the surface of Box 3 and within 3 inches of the surface in Box 4 to observe the effect of these flooded conditions on young plants.

The 55 young plants in Box 3, before flooding, had attained an average height of 5.4 inches and the 57 young plants in Box

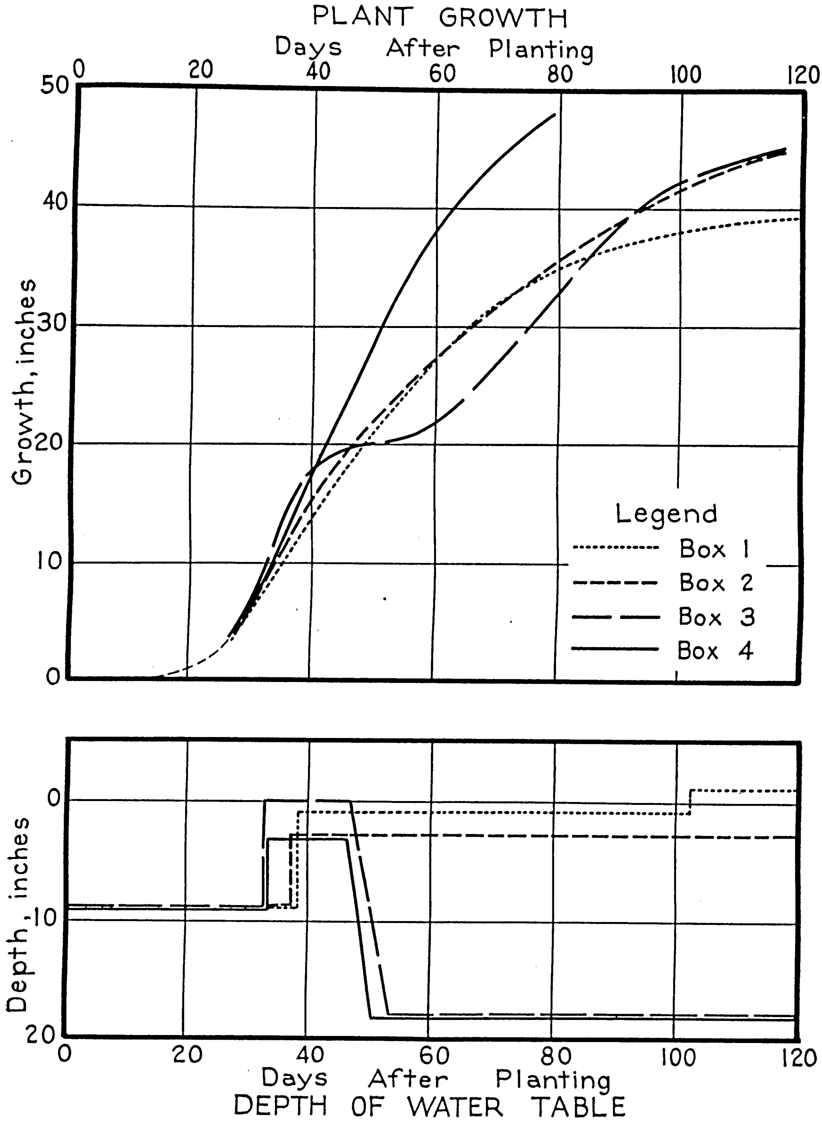
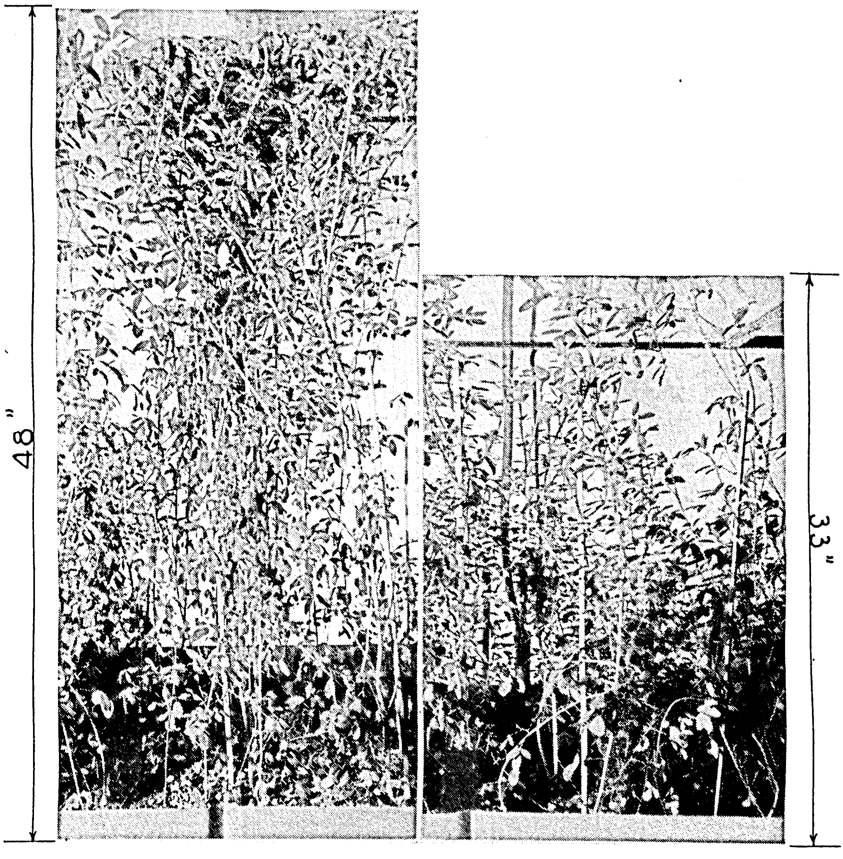


FIG. 7. RELATION BETWEEN GROWTH AND THE HEIGHT OF THE WATER TABLE

NOTE: Upper and lower graphs must be studied together in order to determine growth at any given time under given depth of water table.

4 had reached an average height of 5.8 inches. Within 8 hours after raising the water table to the surface, 30 per cent of the plants in Box 3 showed signs of drooping, and after 2 days about 70 per cent of the plants were likewise affected. The larger, more vigorous plants were the least affected, and it was not until the eleventh day that these stronger plants showed definite signs of distress. After 13 days all plants in Box 3 had lost their sturdy, healthy appearance and had almost reached the point of permanent breakdown of tissue. Their color was poor, the leaves ranging from a light green to a yellow, and some of the stems



Not Flooded **Flooded 13 Days**

FIG. 8. EFFECT ON GROWTH OF FLOODING YOUNG PLANTS (PHOTOGRAPHED 79 DAYS AFTER PLANTING)

were turning from a green to a reddish color. Only a few showed any growth during this flooded period.

The growth of the plants in Box 4 was not hindered by the 3-inch water table. Nearly all of these plants still retained their healthy, sturdy appearance, only 2 showing signs of drooping after 13 days' exposure to a 3-inch depth of water table. The 55 plants in this box showed an average increase in length, during this 13-day period, of 10.6 inches or 200 per cent. The 57 plants in Box 3 during the same period showed an increase in length of only 0.9 inches or an increase of but 16 per cent.

After the plants in Boxes 3 and 4 had been exposed 13 days to the high water table, it was gradually lowered at the rate of 3 inches per day to a depth of 18 inches below the surface.

The upper graph of figure 7 shows the growth in inches, of plants which have been exposed to the moisture conditions given in the lower graph of figure 7. In measuring the growth of plants as designated in these graphs, 3 to 10 of the better plants in each box were marked and their average growth noted. It is obvious from figure 7 that the raising of the water table in Box 4 to within 3 inches of the surface did not materially retard the growth. On the other hand, it is equally evident that the plants did not grow much during the period when the water in Box 3 was raised to the surface. Under the first set of conditions, it took the plants 79 days to reach a height of 48 inches and under the second exposure 117 days to reach a height of 45 inches. At 79 days, when the plants in Box 4 measured a height of 48 inches, the plants in Box 3 had attained a height of only 33 inches (fig. 8). At 79 days and 117 days the

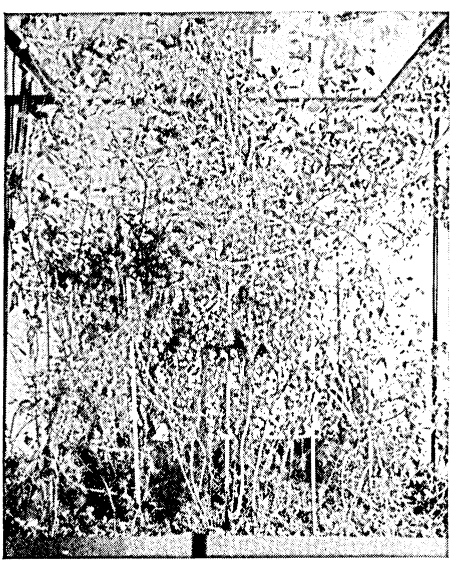


FIG. 9. EFFECT ON PLANT DEVELOPMENT OF RAISING WATER 1 INCH OVER GROUND SURFACE

NOTE: Previous to this exposure plants had grown over a 1-inch water table. Nineteen days of this exposure either killed or seriously wilted the crop. Note also tangled and weak condition of growth. (Photographed 133 days after planting.)

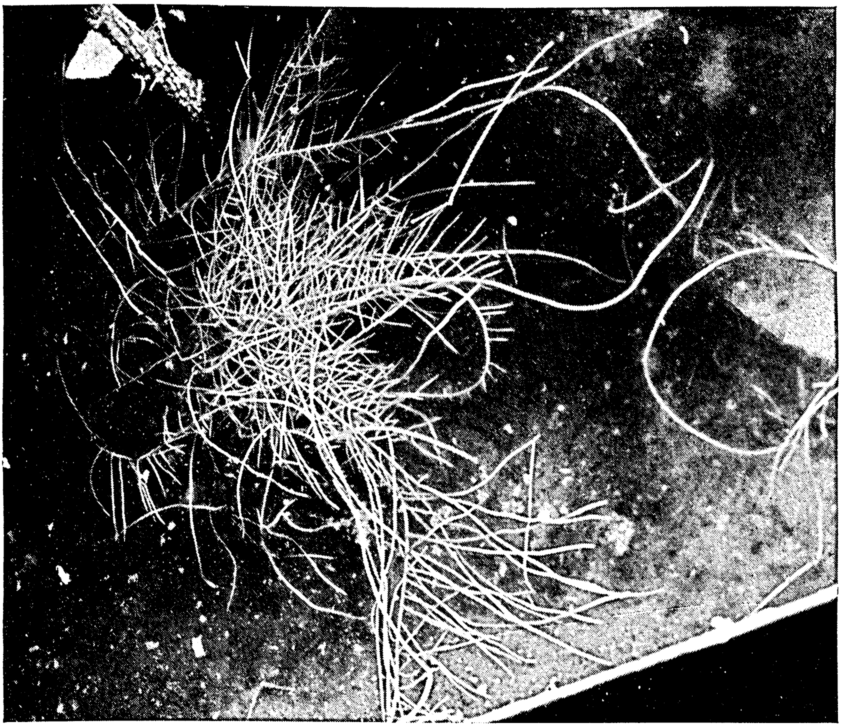


FIG. 10. SUBMERGED ROOTS GROWING UPWARD THROUGH THE WATER TO THE SURFACE SEEKING AIR

plants were cut back to 5 inches, the harvested crops showing the following dry weights: 136 grams for Box 4 and 140 grams for Box 3. The data show that when the surface was submerged in Box 3 for 13 days, its 5-week-old plants required 50 per cent more time to develop the same yield as that developed in Box 4 where the water table was 3 inches below the surface.

At 5 weeks the water table in Box 2 was raised from 9 inches to 3 inches below the surface and left at this high stage to note plant developments. On the third day after the water table was raised, an accident occurred, and the water overflowed the ground surface to a depth of 3 inches. This flooded condition lasted only one day but, from the appearance of the plants, it was sufficient to cause appreciable slowing of growth. In figure 7 the growth of the plants over a 3-inch water table is shown. It took 114 days for these plants in Box 2 to reach a height of 45 inches which was 50 per cent longer than noted for the plants in Box 4 exposed

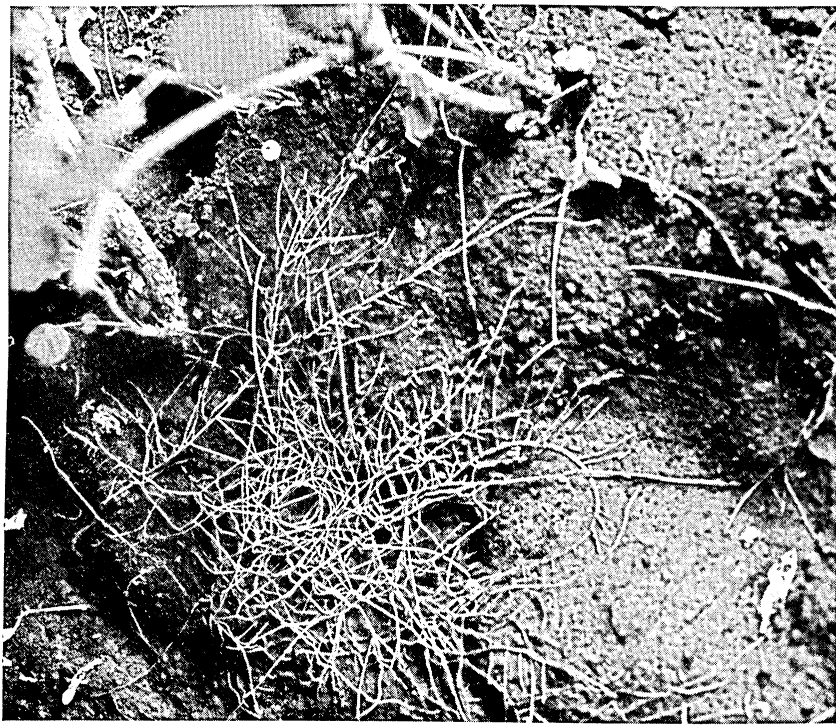


Fig. 11. Roots Shown in Figure 10 Photographed Several Days After the Water Had Receded Below the Surface

only 13 days to a 3-inch water table. When the plants in Box 2 reached a height of 45 inches, they were cut back to 5 inches, the harvested crop when oven-dried weighing 154 grams which is within 10 per cent of the same weight shown for Boxes 3 and 4. With such a high water table the growth was surprisingly good and might even have been better if the plants had not been accidentally flooded.

The plants in Box 1 gave very surprising results. After they had reached a height of 8.3 inches, the water table was raised from a depth of 9 inches to within 1 inch of the surface. It was expected that, with such a saturated condition, the plants would show definite signs of weakening at an early date. After 65 days of such exposure, these plants had reached a height of 39 inches. At this point, while showing no signs of breakdown of tissue, they were not as vigorous appearing as plants grown in the presence of less water. The growth was a tangled mass, due to weak stems, and the color was not the bright green of healthy plants. The growth during the latter part of this wet, 65-day period was at a much slower rate than during the earlier stages.

It was the original purpose in raising the water table to within 1 inch of the surface of Box 1 to note how long it would take for the plants to break down. However, after the 65-day period mentioned, they had not broken down but were still in fair condition. The water table was then raised to 1 inch above the ground surface to observe how long the plants could resist this flooded condition. It took 19 days to bring about a condition that resembled permanent breakdown of tissue (fig. 9). The plants were then cut back to 5 inches and the water table lowered to 18 inches to see whether or not any plants would survive. Again it was surprising to note that most of the dead appearing stubble soon took on new life and sent out new shoots. However, these new shoots did not develop as rapidly as plants that had not been so severely exposed to flooded conditions.

FIG. 12. BASES OF MAIN STEMS SHOWING HOW ROOT SYSTEMS ENTIRELY SUBMERGED FOR 19 DAYS HAVE DIED AND DISAPPEARED

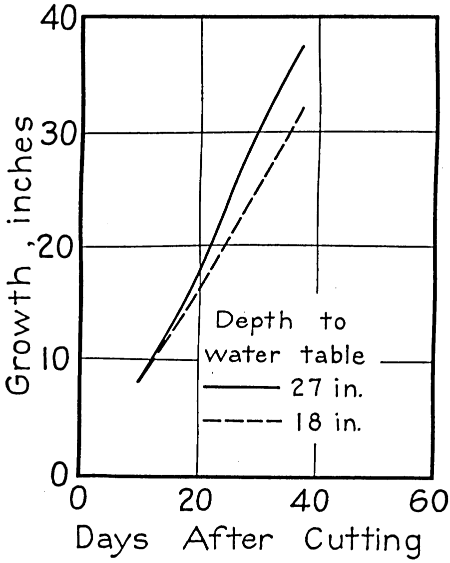


FIG. 13. EFFECT OF SHALLOW DRAINAGE ON THE GROWTH OF PLANTS (AVERAGES FROM BOXES 1, 2, 3, AND 4)

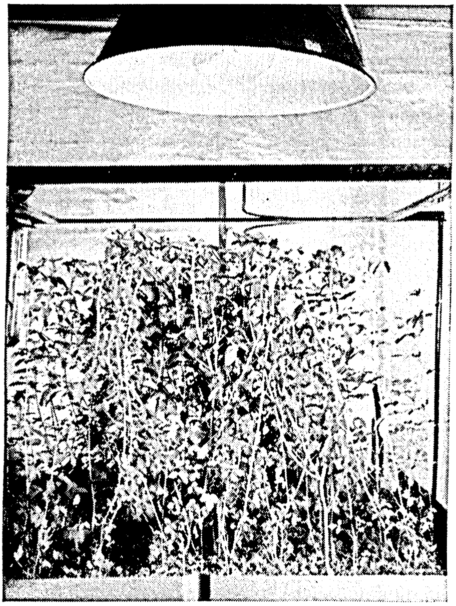


FIG. 14. VIGOROUS STAND OF PLANTS OVER AN 18-INCH WATER TABLE

After the 1-inch layer of water was spread over the surface, the roots reversed their direction of growth and most of them pushed up through to the water surface. (Figure 10 shows the roots of one plant stretching up through the 1-inch layer of water in search of air.) In this way these plants were able to live for weeks under flooded conditions, but their surface roots quickly died after the water receded. (Figure 11 shows them on the surface of the soil after the water had receded below the surface.) In figure 12 may be seen the bases of the main stalk of several plants from this box showing how the original roots in the soil have shriveled up and disappeared during the long exposure to surface flood. The rooting system for all the plants in Box 1 was very shallow being restricted to a thin layer of surface area. By observations through the front windows in each box, it was noted that the roots penetrated into the soil only to the approximate level of the water table.

Shallow Drainage—All of the foregoing tests were made under what would be classified as undrained or waterlogged conditions. The next logical step was to study the influence of a drained condition of the soil. Therefore, in Boxes 1, 2, 3, and 4 following the last cutting back, after growth with a high water table, crops were next grown in boxes with the water table set at 18 inches, and later crops were grown in boxes with the water table set at 27 inches to see if moderately shallow drainage would have any beneficial effect upon the growth of sweet clover. From figure 13 it will be noted that the growth on a 27-inch water table is slightly better than for plants grown on an 18-inch water table. The total height after 38 days over a water table 18 inches deep was 33 inches while that for the same period of growth over a water table 27 inches deep was 38 inches. (Figure 14 shows a vigorous stand of plants grown over an 18-inch water table.)

Rapidity of Drainage—On March 18 the growth in Boxes 2, 3, and 4 was cut to 5 inches. At the time all three boxes were producing good yields with that from Box 2 slightly the heaviest and that from Box 4 the lightest. Three days after cutting, when new growth was apparent, the water was raised above the surface so that all roots in these three boxes were covered, and it was left there for 24 hours. It was then lowered at the following rates per day: Box 2, ¼ inch, Box 3, ½ inch; and Box 4, 1 inch. At the end of 30 days the water table had been lowered to 7½, 15, and 30 inches, respectively, in Boxes 2, 3, and 4. By this time the plants in Box 2 had reached an average height of 28 inches, the plants in Box 3 a height of 32 inches, and in Box 4 a height of 41 inches (fig. 15). From figures 16 and 17 it is obvious that not only were plants taller in Box 4 than

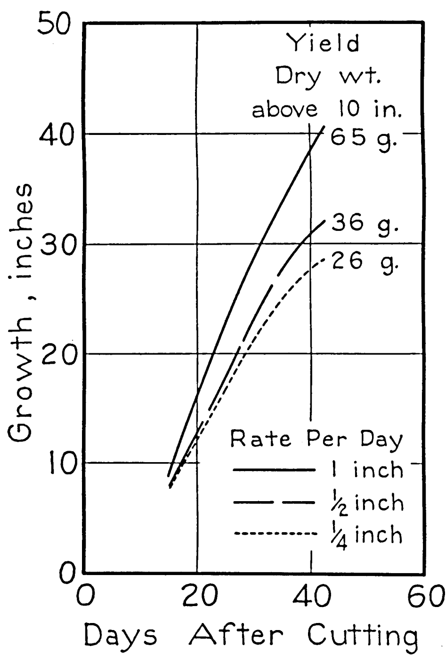


Fig. 15. Effect on Plant Growth of Lowering the Ground Water at Different Rates Per Day

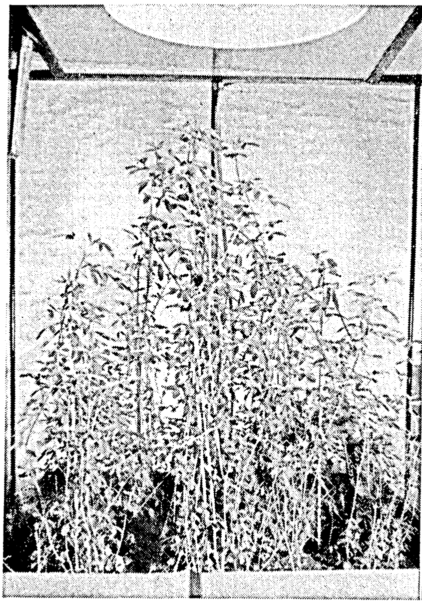


Fig. 16. Plants Grown During 30-Day Period When the Ground Water Was Lowered at Rate of ¼ Inch Per Day

Fig. 17. Plants Grown During 30-Day Period When the Ground Water Was Lowered at Rate of 1 Inch Per Day

in the other two boxes, but that they were a much heavier stand. When the plants in Boxes 2, 3, and 4 were cut back to 10 inches, the oven-dry weight of the harvested crop was 26, 36, and 65 grams, respectively, for the ¼, ½, and 1 inch daily rate of lowering of the water table within the root zone of the plants (table 5). (A duplicate run gave results comparable to the first test.)

It is the author's belief that while so far as the scientific solution of the drainage problem is concerned sweet clover is not of as great importance as various other crops that it is hoped to study later; nevertheless, the study of its behavior under wet soil conditions has definitely indicated a physical set-up and a method of study that can be used successfully to determine the optimum subdrainage condition for any type of crop.

Table 5. Effect on Yield of Lowering the Water Table at Different Rates Per Day (cut 10 inches above surface)

Rate per day of drainage inches	Average height inches	Yield dry weight grams	Dry weight ratios	Appearance of stand
¼	28	26	1.0	Light
½	32	36	1.4	Light
1	41	65	2.5	Heavy

CONCLUSIONS

1. The studies discussed show that biennial white sweet clover can be satisfactorily grown in the laboratory under artificial light if the heat developed by the lamps is intercepted by a water filter placed between the lamps and the plants.

2. Although the growth of sweet clover is definitely stimulated by good drainage, it may be grown successfully on soils that are known to be too poorly drained for satisfactory results with many farm crops.

3. The growth of young sweet clover, 5 to 7 inches high, is not retarded by a water table only 3 inches below the surface for periods up to 2 weeks if afterwards the ground water is lowered. If continuously grown on a 3-inch water table, the matured crop will require a 50 per cent longer growing period to produce a given yield than will be required if the water table be lowered sufficiently to permit a normal rooting depth for this plant.

4. A stand of young sweet clover, 8 to 9 inches high, will not kill when the water is raised to within 1 inch of the surface but will continue to grow at a much reduced rate. Water brought above the surface will cause the plant tissue to break down within 2 weeks.

5. Sweet clover is so water-tolerant that no great difference in growth and yield could be detected as between drainage depths of 18 and 27 inches.

6. Sweet clover flooded for 1 day after cutting and then drained at the rates of ¼, ½, and 1 inch per day shows marked increases in rate of growth and yields through 30 days with the increase in rate of drainage.

ACKNOWLEDGMENTS

The author is indebted to his adviser, Professor H. B. Roe of the division of Agricultural Engineering, whose keen interest in and knowledge of the problem made possible some apparent progress in this study. He also acknowledges his indebtedness to Dr. C. O. Rost of the Division of Soils and Dr. H. K. Wilson of the Division of Agronomy for their many helpful suggestions.

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