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SUB-IRRIGATION IN THE GREENHOUSE.

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I. CONSTRUCTION OF GREENHOUSE BEDS AND BENCHES FOR SUB-IRRIGATION.

A water-tight bed, or bench bottom, is necessary in sub-irrigation, and there are several methods by which this may be secured.

Our first attempt was made with matched lumber or flooring, the joints being filled with white lead. The objection to this method of construction is partly on account of the cost, but more particularly because of the fact that when the boards swell the bottom bulges upward, displacing the irrigating tile and causing leakage.

It has been found that common barn boards, or any rough lumber, answeres better, if the cracks are battened with lath, and a layer of cement is spread over the entire bottom, deep enough to almost cover the lath. About one-third of good cement and two-thirds sand, made quite thin with water, spread on to the depth of about half an inch, and not allowed to dry too quickly, answers the purpose very well. The bottom boards will last longer than when the soil is placed directly upon them, but the supports underneath need to be somewhat nearer together than in the ordinary method of construction, so as to prevent springing of the boards, which cracks the cement.

The greatest difficulty is found in making the sides of the benches water-tight, as no matter how well the side boards are nailed to the bottom boards, they will spring away and cause leakage. To obviate this the cement needs to be put on more thickly at the sides, bringing it up against the side boards two or three inches high, and from one to two inches thick. In fact the office of the cement is to hold the water, while the side boards protect the cement and retain the soil.

In case it is desired to make a bed on the ground the bottom may be constructed in the same manner as an ordinary cellar bottom, except that

the cement need not be as thick. Sometimes the bottom may be made directly on the clay sub-soil, or clay may be brought in for the purpose and no cement used. There may be some leakage in a clay bottom, but not sufficient to do any harm. In all cases there must be a level bottom, or at least the slope must be slight, and all in one direction. Inequalities in the bottom will prevent the proper working of the irrigating tile and result in unequal distribution of the water, hence a perfect grade is essential. In case benches are constructed, the best plan is to use indestructible material altogether.

The interior of one of the houses at the Station, with the bench supports ready for the tile bottom, is shown in Fig. I. It will be seen that the iron gas pipe posts, upon which the purlines rest, support the benches as well as the roof. These posts are of 1¼-inch gas pipe, eight feet apart, a row along each side of the walks and one row through the middle, making five rows in all. There are additional posts between these which reach to the tops of the benches only, making the bench posts four feet apart. To these posts are fastened, by means of clips, 1½-inch gas pipe, laid horizontally, at the proper height for the bench bottoms. The clips are of ⅛-inch strap iron, held with stove bolts, and are quite as good as the more costly cast iron clips. Upon the horizontal gas pipes are laid the T iron supports for the tile bottoms. In this case the supports for the tile are of cast iron, and differ from the ordinary T iron in having the lower flange wider in the middle than at the ends, a lip cast at the ends to hold the bench sides in place, and a concave to rest upon and brace the horizontal pipe supports.

Fig. II shows the same house with the tile bottoms, and sides of the benches ready for the cement and irrigating tile. In this case the tiles are 8 x 12 inches, but any desired size may be used. Tiles of this description are not found in the market generally, but were made by A. Brandstetter, Wooster, O., by dividing hollow brick, which are 4 x 8 x 12 inches, as they came from the molding machine. These are cheaper than the tiles ordinarily used for this purpose, and quite as good as those specially designed for greenhouses. Another form 12 x 24 inches in size is made by the H. B. Camp Co., of Greentown, O. This has the advantage of requiring less cross bars than the other form. Ordinary drain tiles answer very well, but those with six sides are preferred, as if they do not quite fit, when laid side by side, they may be turned so that the angles, or points, touch. Thus when a row is laid across the bench it may be lengthened or shortened, by simply turning some of the tiles. It makes but little difference in the cost, whether large or small tiles are used, but the small sized tiles, usually 2-1½-inch, are preferred, as they take up less space and do not require as wide bench sides.

The sides of the benches are of ordinary roofing slate, 7 x 24 inches in size, and were made by cutting 14 x 24-inch slates in two lengthwise. These slates are held in place by galvanized iron caps, on both top and bottom, and are shown in Figs. II and III. The slate sides rest upon the ends of the cast iron supports for the tile, and are held in place at the bottom by the lips above referred to, and at the top are fastened to the posts with copper wire.

Fig. III shows the same house with the bench bottoms cemented, and the irrigating tiles laid, ready for the soil. The cementing is done in the same manner as described for wooden benches, and it is necessary to bring the cement well up against the sides, as at this point the leakage is most likely to occur, although the slate sides do not spring outward in the same manner as board sides.

The irrigating tiles may be laid lengthwise or crosswise the beds, but about fifty feet is the greatest length of tile that will work satisfactorily on a level, and if the runs are to be longer than this, there should be one or two inches fall to each fifty feet. It will be necessary, however, in case there is a fall, to check the water at intervals, in order to prevent a too rapid flow towards the lower end. This may be easily done by inserting strips of tin into the joints as often as need be, so as to partially intercept the flow, and to cause the water to run out at the joints wherever needed. When properly laid, rows of tile several hundred feet in length could be made to work satisfactorily, but we have had the best success with short runs of tile, laid crosswise the benches. Instead of using elbows of sewer pipe as shown in the cut a cheaper plan is to employ common tile altogether. In this case, the end of the outer tile is raised so as to come above the top of the bench, in order to admit of inserting the hose in watering. When the tiles are laid crosswise the benches, several may be watered at once by means of a piece of gas pipe with holes bored at suitable distances. When the tiles are laid, they are simply placed end to end, and no cement is needed, although it is sometimes used, to prevent the tiles becoming displaced in filling the benches with soil.

Gas pipe, with holes bored at intervals, has been used with success, also a pipe, called "structural iron pipe." This differs from ordinary iron pipe in having a slot along one side. Where the slot is nearly closed, so as to not allow the water to flow too freely, this pipe answers very well, but 2½-inch drain tiles are cheaper than anything else and are perfectly satisfactory. These tiles are, of course, removed and put in place again, each time the soil in the benches is renewed. Another thing in favor of 2½ or 3-inch tiles, is that the capacity is sufficient, so that it may be filled quickly and the operator may go on to another tile, allowing the water to soak out into the soil, knowing that enough has been given to

last several days; but if iron pipes are used the size must be small because of the cost, and the watering must be more frequent in consequence.

II. HISTORY OF SUB-IRRIGATION IN THE GREENHOUSE.

The first suggestion of sub-irrigation in the greenhouse was made by E. C. Green and W. S. Turner, assistants in the horticultural department, and grew out of an attempt to prevent the lettuce rot. A few lettuce plants were set in a box, in which a tile was so placed as to admit of watering, without wetting the foliage, the purpose being to test the theory that wetting the foliage induces or favors the development of rot. The lettuce in the boxes grew so finely that the experiment was enlarged, in order to test the effect of that method of watering on the growth, as well as to determine the relation of sprinkling the foliage to the health of the plants.

The further development of the plan is due to the combined efforts of the Horticulturist and assistants, E. C. Green and W. S. Turner. The experiments were begun in 1890 and carried on two years in the greenhouses first built by the Station and now occupied by the horticultural department of the State University. The removal from Columbus to Wooster caused a suspension of the work one year by the Station, although Mr. Turner who remained as foreman in the horticultural department of the University, repeated the experiments on a somewhat larger scale, the results of which have been published in various periodicals by Professor W. R. Lazenby and others. These experiments were first mentioned in the annual report of this Station for 1891, and a report of progress was made in Bulletin 43, September, 1892, and again in the annual reports for 1893 and 1894.

In Bulletin 33, of the West Virginia Station, Professor F. W. Rane gave an account of his experiments in the same line.

The Horticulturist of this Station has prepared a chapter on sub-irrigation in the greenhouse, for a work on greenhouse management by Professor L. R. Taft, and has made brief mention of the progress of the work in the proceedings of both the State and Columbus horticultural societies. A newspaper bulletin was prepared early last season, giving brief instructions as to the method of construction of benches for the purpose, but there have been numerous calls for further information on the subject, both as to results of experiments with various crops, and methods of operation.

The literature of the subject, which is comprised in the publications named above, except a few short newspaper notices, is not only scattered, but is incomplete as to details, hence it seems best to make another report

of progress, especially since it may take some time to bring the experiments to a satisfactory state of completion, although enough is already known to warrant giving the facts to the public.

It was with some degree of hesitancy that the first results were announced, as it was thought that in some cases, at least, bad effects might follow sub-irrigation. According to accepted theories, plants could not long continue to thrive when watered by this method, since no provision is made for bench drainage, and for this reason the publication of results has been somewhat delayed. Now that the matter is better understood, fears on this score seem to be groundless, hence there is no longer any doubt as to the propriety of giving out the results and recommending the practice. The belief that bench drainage is essential gave birth to these fears, but that it is not essential in sub-irrigation has been fully demonstrated.

It has been feared also that in sub-irrigated houses the air might be so dry that plants would not thrive, and that the red spider would find such conditions very favorable for rapid multiplication. The relative humidity of sub-irrigated and surface watered houses has not been determined, but some preliminary experiments fail to show any decided difference, besides we have seen no suffering of the plants because of insufficient moisture in the air.

Nearly entire houses, where vegetables were grown, have been devoted to sub-irrigation for a sufficient time to show that the anticipated danger does not exist, so far as they are concerned, but the test has not been so complete with flowering plants.

With vegetables, no attention has been given to the red spider, as it is not particularly troublesome on such plants, and with florist's stock the usual plan of syringing the foliage has been followed, but that the red spider is worse in sub-irrigated than in surface watered houses we cannot, at present, either affirm or deny.

That the watering of the surface of the soil, incident to the necessary syringing, detracts from the effect of sub-irrigation is admitted, however. For this reason sub-irrigation may prove to be of greater value to vegetable growers than to florists, but our experiments have progressed sufficiently far to show that it is the best method of watering in all cases, where plants are grown in beds or on benches.

The importance of sub-irrigation in the greenhouse is sufficient to warrant a full discussion of the subject, but the results with some of the crops which may be grown by this method must be reserved for a future bulletin. To facilitate a clearer statement of the case some general propositions will first be offered, after which the results with special crops will be discussed.

III. GENERAL PROPOSITIONS REGARDING SUB IRRIGATION IN THE GREENHOUSE.

(1.) *Watering by sub-irrigation in the greenhouse is more cheaply done than by the ordinary method:* Watering by this method saves both labor and water, but in most cases the first item alone is worth considering. As explained in another connection, the rows of irrigating tile are laid two and one-half feet apart on the benches, thus making it possible to water a strip of the bed of the above width, and of whatever length the row of tile may happen to be, equivalent in some cases to 100 square feet or more, without the operator changing position. It is possible, however, for one person to attend to several rows of tile at the same time, and to thoroughly water a house 20 x 100 feet in half an hour. This is not only less time than the same space could be watered in the ordinary manner, but the watering needs to be done less frequently. The saving of labor depends almost wholly upon the completeness of the arrangements for watering, and no doubt in large establishments this saving might be carried much farther than now seems to be possible, even to the extent of reducing the cost of watering to less than one-fifth of the present necessary outlay.

The arrangement is really self regulating, after the hose is inserted into the tile, as the water simply runs out through the joints of the tile and permeates the adjacent soil, thus requiring no care on the part of the operator in its distribution. An inexperienced hand can do as good work as the most expert, as he need give no heed to the work, further than to insert the hose and withdraw as soon as the tile is filled, thus making it possible to employ cheap labor.

(2.) *Watering by sub-irrigation in the greenhouse is more efficiently done than by the ordinary method*: When plants in beds are watered by pouring water on the surface of the soil, much care is required to make the distribution perfect, as well as to give the requisite quantity. Attention to detail is necessary in the first and a thorough knowledge of the needs of plants in the second. Should the knowledge be wanting, or the details be omitted, bad effects are sure to follow, and the damage is not easy to repair.

If insufficient water is given at first the bottom soil is apt to become dry and hard, a condition not easy to remedy, even by excessive watering in the future. Such a state of affairs cannot occur with sub-irrigation, if the beds are properly constructed, nor can there be any dry spots in the beds.

Excessive watering on the surface produces a condition not less objectionable, which will be referred to more particularly in another place,

but in this connection it may be said that plants do not suffer from too much water in the soil when the excess is below and the surface is loose and friable, as when these conditions are reversed. That is, a water logged condition of the soil is less likely to occur by sub- than by surface irrigation, and by the first named method the water is put where it is most needed, and where it can do the least harm, in case too much is applied for the present needs of the plants. A reasonably careful man, with almost no experience, can do better work in watering plants by sub-irrigation than the most skillful can by the ordinary method.

With the lettuce crop, the difficulty of watering becomes greater as the plants increase in size. If the foliage is sprinkled it is kept constantly wet, thus favoring the development of the rot, and if the hose is inserted between the plants, more or less injury is done them, besides the surface of the soil becomes puddled where the hose is pushed back and forth. When the plants reach maturity it is a difficult matter to give them as much water as they need, as the soil has become so compacted as to prevent free and uniform percolation. By sub-irrigation the water can be given as easily in the last stages of growth as the first, and in any quantity desired, with full assurance that it will be distributed evenly.

(3.) *Where sub-irrigation is practiced in the greenhouse the soil does not become compacted as by surface watering, but retains its original loose, friable condition, even without frequent stirring, nor does it become mossy, water logged and sour:* This applies more particularly to soil having a considerable per cent. of clay, but the same is, in a measure, true of all classes of soill. With some classes of plants the foliage must be syringed to keep the red spider in check, and in this manner the soil is watered more or less, causing a crust to form on the surface, which must be broken by digging; but the compacting of the soil is directly proportioned to the quantity of water applied to the surface. No matter how frequently the soil is stirred, where surface watering is practiced, it cannot be kept in as good condition as where sub-irrigation is followed, and by the latter method the working of the soil is made comparatively easy.

Examination of sub-irrigated beds shows that the surface of the soil is loose and friable, becoming firmer below, where it often appears to be somewhat soggy. This latter condition disappears as the soil dries out, and hardening does not occur. The soil may be worked at any time without danger of making it hard, as the surface is always comparatively dry, unless the watering has been excessive a short time before. We have found that soil which contains so much clay as to be unfit for use in the greenhouse, where surface watering is practiced, answers very well for sub-irrigation.

(4.) *Plants are less liable to suffer from overwatering and diseases by sub-irrigation than where the water is applied to the surface:* The possibility of overwatering by sub-irrigation may be tentatively admitted, but in practice we have not found the limit to the quantity of water which may be safely used. The quantity applied at one time may be in excess of the needs of the plants for several days and no harm will follow. We have never injured a plant by this method of watering, nor have we seen any symptoms of ill health which plants often exhibit when watered too profusely and frequently on the surface of the soil. In practice we have used water liberally, and have been surprised to note the quantity, not only which may be used without injury to the plants, but which seems to be necessary for the best results.

Whether to water sparingly, but frequently, or less often and profusely, has not been determined, but no bad results appear to follow when the beds are saturated and then allowed to remain several days and to become partially dry before another application is made.

We have found that sub-irrigation is not only safer than surface watering, but that, on clay soil at least, it is the only method by which plants can be given all the water they require. Plants will thrive on less water by sub- than by surface irrigation, but they will also use much more, if it is applied, hence the greater possibility of forcing growth by the former than by the latter method. More attention has been given to comparative growth, on surface and sub-irrigated plots, than to relative prevalency of diseases; but lettuce rot has shown a preference for surface watered plants, in some cases in quite a marked manner. The injury done to roses by nematodes has been much greater where the plants were surface watered than where sub-irrigated. Where the latter method has been practiced the plants have almost outgrown the disease, but have succumbed where surface watered.

(5.) *All classes of plants which may be grown upon greenhouse benches thrive better by sub-irrigation than by the ordinary method of watering:* The demonstration of this proposition will be found under the head of results of experiments, but it will not be out of place to assign some reasons which appear to be valid, although not offered as a full and sufficient explanation.

No doubt the physical effect of sub-irrigation upon the soil, which has been referred to, has an important bearing upon the matter, for it is well known that the more porous and friable the soil can be kept the better it is for the plants growing in it. Vegetable matter is often added, and rotted sod is used for the purpose, as well as sand and cinders. It is true that sub-irrigation does not produce this loose, friable condition of the

soil, but simply helps to retain or to preserve it, thus making continuous aeration of the soil possible.

The mere presence of the tile in the beds has been supposed to have some beneficial effect in promoting aeration, but when placed in surface watered beds they have not appeared to have any effect. More or less air enters the soil through the tile, along with the water, but the surface of the soil offers a much greater area of exposure, and being more permeable than the lower portions it follows that aeration takes place mostly from above.

In the light of well known facts regarding soil aeration it can hardly be disputed that sub-irrigation is in this manner beneficial, but there are other potential factors. Uniformity and constancy in the supply of moisture to the roots of plants are favorable to growth, and these conditions are assured with sub-irrigation. That plants grown by sub-irrigation take up more water than those watered in the ordinary manner may be inferred from the fact that they grow faster and have a greater leaf development.

It has been urged against this method of watering that unless sprinkling is resorted to undue dryness of the air will result, but it is by no means certain that such a condition occurs, and if so it has not been shown to be detrimental. Plants thrive in arid regions where the air is dry, if water is supplied to the roots; moreover, we have some excellent experimental testimony which ought to set at rest all such fears.

The Botanist of this Station, A. D. Selby, has called attention to and kindly translated the following extract from Frank's *Krankheiten der Pflanzen*, page 310:

"The nutrition and production of plants are diminished in an atmosphere constantly moist. This depends upon the fact that in air saturated with water vapor the plants cease to transpire. But the stream of transpiration water that goes through the plant is the medium in which the food materials from the soil are conducted into the plant, because precisely these enter into the plant dissolved in this water, but remain behind in it when the plant again gives off pure water in vapor form and thereby makes room to take up a corresponding quantity of new food materials from the soil. In tobacco plants the diminished production of mineral constituents, as well as organic plant constituents, in consequence of suppressed transpiration, has been observed, the plants whose transpiration was obstructed, furnishing, in comparison with those under otherwise the same condition, but with unhindered transpiration, less mineral matter, less nicotine, oxalic acid, citric acid, malic acid, pectose, cellulose and protein, but, on the other hand, much starch. It appears to follow from this that the suppressed transpiration has as a consequence a diminished introduction of mineral matter from the soil, but does not hinder the formation of starch grains in the leaves from carbon dioxide and water. Therefore only the production of those plant constituents is influenced to whose origination constituents of the soil food materials are required."

The greater leaf development of sub-irrigated plants indicates that they transpire more water than those that are surface watered, but the

method of watering the latter may be the means of introducing more water into the air than is really needed by the plants, and the efforts of gardeners to produce a moist air in the greenhouse may often be misdirected. It has been demonstrated by the author above quoted that plants have become "drawn" in an over moist atmosphere, and other ill effects follow also, such as dropping the lower leaves, etc. Regarding the general statement of the proposition we have yet to find any exceptions. Sub-irrigation may not be the best method of watering all classes of plants, because of practical difficulties in some cases, but the fact remains that we have found no plants that do not thrive better by this than by the ordinary method of watering. Our experiments have included plants most commonly grown on greenhouse benches, such as lettuce, radishes, cucumbers, tomatoes, spinach, parsley, cauliflower, beets, sweet peas, smilax, roses, gladioli, carnations, violets, chrysanthemums and ferns. As might be expected, these are not all benefited in the same degree by sub-irrigation, but all are improved by it, and sufficiently to warrant its use wherever practicable.

IV. THE RESULTS OF EXPERIMENTS IN SUB-IRRIGATION.

The results of experiments which follow in this and succeeding bulletins may be regarded as the demonstration of proposition five. The full results may not be ready for some time but will be given out as soon as possible.

LETTUCE.

The first experiments in sub-irrigation, as before stated, were with lettuce plants, grown in boxes about 16 inches square, and with about 10 inches of soil. These boxes were water-tight, and in order to obviate the necessity of wetting the foliage of the plants, a 2½-inch drain tile was placed in an upright position, in each box, so that the plants could be supplied with water by simply pouring it into the tile and allowing it to percolate through the soil. The leaves of the plants were not watered, nor was the surface of the soil.

The object of the experiment was simply to test the theory that wetting the foliage is favorable to the development of lettuce rot, hence care was taken to supply water to the roots only.

Because of the belief that drainage is necessary for plants growing in pots, boxes or beds, it was with some surprise that the plants were not only found to do as well by this method of watering as by the one ordinarily practiced, but even better. There was a gain of weight in favor of the sub-irrigated plants equal to 25 per cent.

Experiments on a larger scale were planned at once, and a bed 7½ x 10 feet was prepared on the ground, and another of the same dimensions in the center of the middle bench in one of the houses. Sections of the same bench were reserved on either side for surface watering. The bottom of this bench was made water-tight by laying matched flooring in white lead. 2½-inch drain tiles were laid two and one-half feet apart crosswise the benches, and holes were bored through the sides to admit the hose in watering. The usual quantity of soil was then placed on the bench and the plants set out. The first trial of the beds was even more in favor of sub-irrigation than in the boxes.

The second season another section was taken in the house alongside the first, also some portions of the side benches. The result in every case was in favor of sub-irrigation, the highest gain being 100 per cent. above surface watering. In these experiments there was a very uniform stand and growth of plants in both plots, but those in the sub-irrigated beds stood about twice as high as the others and the weight was double. In order to illustrate the difference, two plants were taken, one from the sub-irrigated bed weighing 10 ounces, and the other from the surface watered bed weighing five ounces, and photographed. These were representative plants from the respective beds, being as fair an average as could be taken, and are shown in Fig. IV.

It may be admitted that plants quite as large can be grown by surface watering, as 10 ounces has often been exceeded, but a longer time is required in which to do it.

It should be here explained that all of the weights given of lettuce are of the fresh plants, as soon as cut, and before washing. It is customary to wash lettuce before weighing, when it is sold by weight, according to the practice in some markets, and had this plan been followed the weighings would have been much heavier, but as this would have been a source of variation and error, it was thought better to follow the plan named. In some trials the results were not so marked, but in all cases there was a decided gain in favor of sub-irrigation, but as these earlier results agree with those obtained recently, it is not necessary to give them in detail. In one sub-irrigated bed the gain in a single crop was sufficient to pay the cost of putting in a new bench bottom, counting the value of the crop at 15 cents per pound, but in all cases the outlay for reconstruction was more than reimbursed the first season. In constructing the houses at Wooster nearly all the benches were made water-tight for sub-irrigation, and only a small part was left for surface watering, the reverse of the plan at Columbus. Three houses, each 20 x 100 feet, have been devoted almost wholly to lettuce, nearly all of which has been sub-irrigated. A middle section in each house has been reserved for

surface watering and the end benches are divided, half being watered by one method and half by the other. Incidentally, this arrangement may be referred to as affording an opportunity to note the behavior of plants in houses where the moisture in the air, in addition to the normal quantity, comes almost wholly from plant transpiration.

In the following table the results with a number of varieties are given. This was not intended as a variety experiment, as those in the list are not comparable in the manner presented, since some are varieties which form heads while others do not. All that it is intended to show is the relative development of each variety by the two methods of watering. In this experiment each lot was carried through the entire season of growth by the method indicated. That is, the sub-irrigated plants were treated in that manner from the time the seed was sown until the crop was harvested. The particular method of operation is described more fully under the head of cultural notes. The surface watered plants, on the other hand, were surface watered during their entire season of growth. This is referred to particularly because it is not the plan which has been followed in the greater number of our experiments. It will be seen that the average gain in favor of the sub irrigated plots was about 100 per cent.

TABLE I.—THE RESULTS OF SURFACE AND SUB-IRRIGATION WITH TEN VARIETIES OF LETTUCE.

Variety.	Surface watered.		Sub-irrigated.	
	Number of plants.	Weight.	Number of plants.	Weight.
		Ounces.		*Ounces*
Chicago Forcing	5	11	5	22
Denver Market	5	8	5	12
Tilton's White Star	5	11	5	32
Henderson's N. Y.	10	22	10	40
Hanson	10	18	10	48
Grand Rapids	25	80	25	208
Iceberg	15	32	15	47
Big Boston	15	21	15	51
Large Boston	10	14	10	31
Rawson's Hot House	15	23	15	41

In Table II the separate results of 15 experiments are given. It is not necessary to discuss these results in detail, for they agree in the main, although there is some variation, as might be expected, owing to the varying circumstances under which the experiments were conducted—early and late in the season, in different houses and by different men—nor would it add to the force of the argument to give a greater number of

examples. No effort has been made to select examples, further than to secure a fair average, rather than to present the highest or the lowest. The average gain of the sub-irrigated over the surface watered in the above cases was a little more than 40 per cent. This increase in weight was made in a little more than six weeks, or from the time the plants were set in the benches to the end of the experiments. That is, all of the plants were sub-irrigated while growing in the flats, or during about half of their period of growth, and not until they were planted in the benches was surface watering commenced. This is a less favorable showing for sub-irrigation than is made in Table I, by the plan above described of carrying the plants through their entire period of growth by the respective methods of watering.

TABLE II.—RESULTS IN FIFTEEN SUB-IRRIGATION EXPERIMENTS WITH GRAND RAPIDS LETTUCE.

Experiment.	Surface watered.		Sub-irrigated.	
	Number of plants.	Weight.	Number of plants.	Weight.
		Ounces.		*Ounces.*
I	140	474	140	637
II	100	374	100	512
III	75	287	75	383
IV	100	299	100	453
V	55	297	55	340
VI	100	545	100	602
VII	25	132	25	176
VIII	25	121	25	130
IX	35	212	35	242
X	150	477	150	572
XI	107	554	107	644
XII	144	262	144	337
XIII	32	107	32	147
XIV	96	280	96	380
XV	160	156	160	452

In the above examples the surface and sub-irrigated plots were side by side, but a more satisfactory plan is to alternate the plots. This, however, cannot be extended very far, as the difference in heat in the two ends of a house is considerable. A very good plan is to take a section of a bed in the middle of a house and treat by one method of watering, while two sections of the same size on either side are treated according to the other method. This has been done in several cases and some examples are given in Table III. In these experiments the plants were treated in the same manner as those in the experiments above mentioned, *i. e.*, all were sub-irrigated until they were planted in the benches. After

that time Sections A and C were sub-irrigated, and Section B was surface watered. The average gain of the sub-irrigated plots over the surface watered was about 38 per cent., or very nearly the same as average of the 15 experiments in Table II.

TABLE III.—COMPARISON OF SURFACE WATERED SECTIONS WITH SUB IRRIGATED SECTIONS ON EITHER SIDE, 75 GRAND RAPIDS PLANTS IN EACH SECTION.

	Section A, sub-irrigated.	Section B, surface watered.	Section C, sub-irrigated.
Experiment I.....	Weight, 385 ounces...	Weight, 325 ounces...	Weight, 420 ounces
Experiment II.....	" 487 " ...	" 329 " ...	" 496 "
Experiment III.....	" 308 " ...	" 229 " ...	" 345 "

In all of the experiments thus far referred to, but one point has been considered, and that is the increase in weight by sub-irrigation. Aside from the relative prevalency of disease in plants treated by the two methods, there are but few practical questions.

Although not a matter of much practical importance, some interest attaches to the fact that sub-irrigated lettuce is earlier than that grown in the ordinary manner. It does not really come to maturity any earlier, if by that is meant the stage at which the plants cease to increase in weight, caused by the dying of the lower leaves, but it does reach a marketable size sooner. It is customary to allow the plants to stand as long as they continue to improve, but in case it is desirable to cut before that time it will be found that the sub-irrigated lettuce will be a week to ten days ahead of the other.

Should the size to which surface watered lettuce can be grown be set as a standard, and the sub-irrigated cut when it reaches that size, it will be found that the latter will be ready four to six weeks from the time of planting in the beds, and the surface watered must be allowed to remain from six to eight weeks to attain the same size. Whether we reckon in this manner, or by the actual weight of the crops harvested during the season, there is a gain in one season of about one crop by sub-irrigation. Both the yield and price vary, of course; but for a house 20 x 100 feet the difference in a single season between surface and sub-irrigation might safely be estimated at from $50 to $ 00. The latter figure might not be reached, except on very heavy clay soil, and on soil specially adapted to lettuce the difference might be even less than the lowest, but experience has shown that it is more likely to exceed than to fall below $50

The difference is likely to be greater with new beginners than with those of experience, as more skill is required to manage a crop by surface

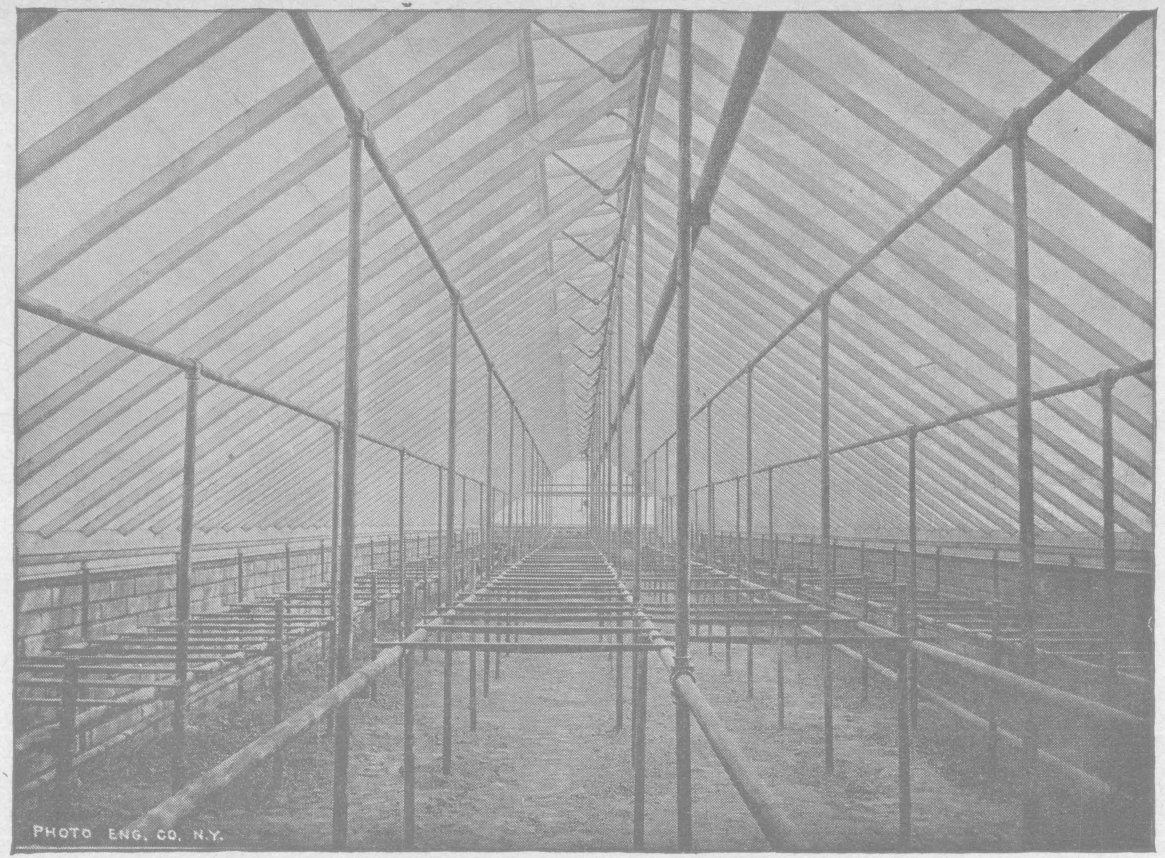

FIG. I.—INTERIOR OF GREENHOUSE, SHOWING IRON SUPPORTS READY FOR BENCH TILE.

FIG. 11.—INTERIOR OF GREENHOUSE, SHOWING TILE BOTTOMS AND SLATE SIDES TO BENCHES.

FIG. III.—INTERIOR OF GREENHOUSE, SHOWING BENCHES WITH BOTTOMS CEMENTED, AND IRRIGATING TILE LAID.

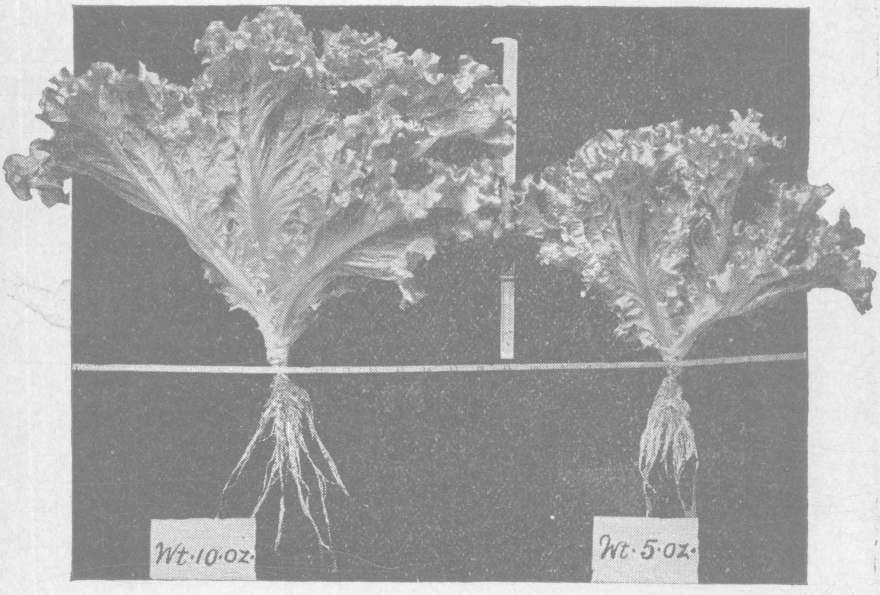

FIG. IV.—SUB- AND SURFACE IRRIGATED PLANTS OF THE SAME AGE.

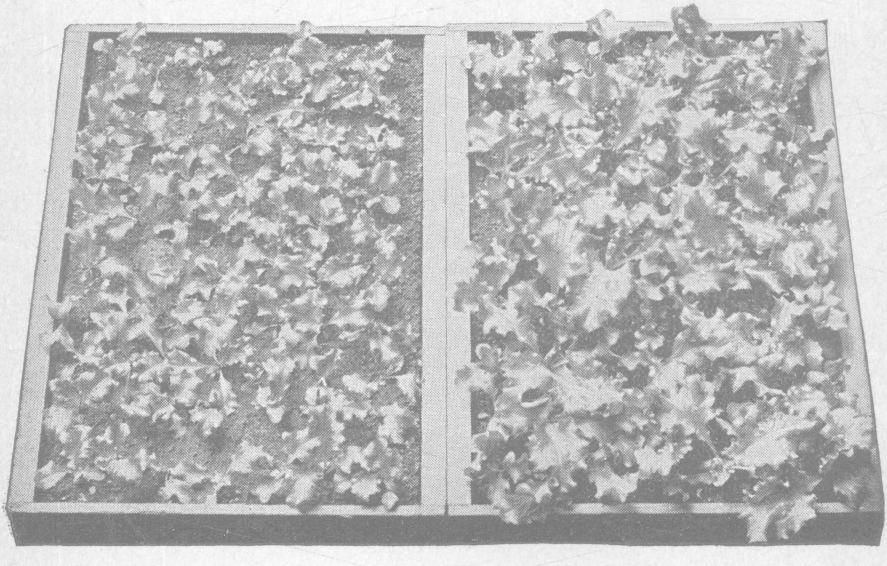

FIG. V.—SURFACE AND SUB-IRRIGATED LETTUCE PLANTS, GROWING IN FLATS.

than by sub-irrigation. It is an established fact that good head lettuce cannot be grown on heavy soil by surface watering, and the same is, in a measure, true of all varieties. It is evident, therefore, that sub-irrigation greatly enlarges the possibilities of lettuce culture under glass. It not only makes the work easier for new beginners but it makes it possible to use soil that would otherwise be precluded. More than that, it solves the problem of meeting competition from the South, which competition bids fair to ruin the business of vegetable forcing at the North, unless improved methods are adopted by Northern gardeners.

V. SUGGESTIONS REGARDING THE CULTURE OF LETTUCE UNDER GLASS.

This ground has been partially covered in a previous bulletin, but the interest in lettuce culture is growing, and inquiries are quite frequent concerning methods and appliances.

In the first place, local conditions should not be overlooked, such as soil and the market requirements. If the market demands head lettuce, then it is of the utmost importance that the soil should have a considerable per cent of sand, and at the same time be sufficiently fertile and have capacity for holding moisture. Non-heading sorts, like the Grand Rapids, are not so particular as to soil, but it is a difficult matter to grow any kind on a soil with much clay in it, by surface watering, and even if sub-irrigation is practiced such soil should be avoided. It would be futile to attempt to grow lettuce according to methods in vogue in the East on a heavy clay soil. Swamp muck, composted with one-fourth or one-half horse manure, answers very well for either surface or sub-irrigation, particularly for the latter. It has the advantage of being light and easily handled, and never hardens; moreover, it has considerable capacity for water.

The addition of fine sand will greatly improve a clay soil, and it is advisable, if such soil is used, to take it from an old fence row, using the sod only. It may be inferred from the above that lettuce may be successfully grown on almost any soil, and such is the fact, if conditions are thoroughly studied and the details carefully looked after. Nevertheless it is better to select a soil naturally adapted to the purpose if possible, but in any case such artificial means as composting and sub irrigation ought not to be neglected.

Regarding varieties but little need be said, as but very few are suitable for the purpose. Of those that form heads a good strain of the Tennis Ball is the best, but in this section it is not best to grow any of this class. Head lettuce is more particular as to soil, more subject to rot, requires more room and is longer in coming to maturity than Grand

Rapids or kindred sorts. In Eastern markets none but head lettuce will sell, but happily for gardeners in this and surrounding sections no such whimsical discrimination is made. Occasionally there is inquiry for head lettuce, but the Grand Rapids is usually taken as a substitute without complaint, and such being the case there is no need of growing any other kind. There is no other variety that will compare with it for profit in the region west of the Alleghenies, hence it is not necessary to offer any further argument to convince gardeners, within these limits, that it is the kind to grow.

Lettuce may be grown at any time of the year, but it flourishes best after midwinter until spring, and the demand is usually best at this time. But it is advisable to occupy the houses as early and as long as possible, hence the first sowings should be made in August or September. In large establishments it is customary to sow the seed in the beds that are used for the regular crop, and to transplant the young plants into the same beds, but in most cases it is better to sow in flats and to transplant into flats the first time also. The flats in use here are 16 x 24 inches, and two inches deep. These flats have slatted bottoms, and when placed in a shallow vat of water the soil in them quickly becomes saturated.

The labor of giving a single watering in this manner is more than is required to sprinkle the surface, but the watering does not need to be repeated so soon. The total labor required is about the same by the two methods, but watering by soaking, or by sub-irrigation, gives better results than sprinkling, hence it is recommended wherever practicable. It is by no means so impracticable on a large scale as may seem, for with vats, or water benches, conveniently located, the watering is easily done, and so thoroughly as to preclude any possibility of the plants suffering for water for several days.

Fig. V shows two flats, with lettuce plants 2 x 2 inches apart, those in the flat on the left having been watered in the usual manner, and those on the right by the method described. The actual difference is greater than appears in the picture, as the relative height is not shown, simply the leaf development horizontally. It is not unusual to increase the size in this manner 50 per cent. or more in the three or four weeks which the plants occupy the flats from the time of the first transplanting to the second, or when they are set in the beds.

In case flats are not used the plants may be set in beds and sub-irrigated in the usual manner, and thinned at the proper time, or all transplanted, as desired; but in any case it is advisable to sub-irrigate them during the entire period of their existence.

It is not advisable, in any case, to sow the seed where the plants are to stand until mature, as too much space is wasted in this manner before the plants are large enough to occupy it all. The proper plan is to keep the plants crowded as closely as they will bear, so as to occupy the space fully. There is a limit to profitable crowding, however, and 2 x 2 at the first and 6 x 7 inches at the second transplanting may be set as the lowest limit for the Grand Rapids. Head lettuce should be planted 4 x 4 inches apart at first, and 8 x 8 at the final transplanting, when set in beds or benches.

The plants should be kept growing from the start, and should receive no check for want of water. They may be forced as rapidly as possible by means of fertilizers and frequent stirring of the soil, but not by too high a temperature—50 to 60 degrees in the day time, and about 10 degrees lower at night, is about right. If the houses are kept much warmer than this, particularly at night, the lettuce rot is almost sure to injure or destroy the plants. If the foliage is kept wet by frequent sprinkling the rot is more likely to prevail than if no water is applied to the leaves, but it will occur in any event, if the house is kept too warm.

The depth of the soil in the beds, and the position of the beds, whether on the ground or on benches, is a matter of considerable importance, if surface watering is practiced, but less so with sub-irrigation. Near Boston, where head lettuce is grown extensively, the beds are on the ground altogether, and the soil is a foot or more in depth. There is a saving of the cost of benches by this method, and the soil retains moisture better than a smaller quantity would on a bench. For this reason it is better to have the beds on the ground where surface watering is practiced, but for sub irrigation it does not matter in the least where the beds are, and six inches of soil is as good as more. As a matter of economy it is better to place the beds on the ground, except where the space under the benches can be profitably utilized, as in growing mushrooms, pie plant, etc.

In lettuce houses it is not so important to have the plants near the glass as with some other crops, but in any case it is well not to place the roof any higher than need be, and to avoid shading the plants by the walls of the house. Ventilation is a matter that needs special attention in lettuce growing, for the same reason that overheating must be avoided. During very cold weather in winter is a critical time with the lettuce crop, especially if the days are dark and cloudy, for the reason that ventilation is apt to be neglected. The still, damp air gives the fungus, which causes the lettuce rot, a good chance to grow, and owing to the necessity of constant firing, the temperature is more likely to be too high than too low, hence a bad attack of the rot often occurs at such times.

It is safer, in such cases, to run the risk of reducing the temperature too much by frequent ventilation than to take the chances of the rot getting a start. Both extremes are to be avoided, but especially the one which favors the development of the rot.

Watering by sub-irrigation may need some explanation, but the method is so simple that a very short experience will enable any one to understand how to operate it. As in surface watering, the needs of the plants are to be studied, and water is to be supplied when they require it, as shown by the appearance of the foliage. Plants are not to be allowed to wilt, however, before watering, but the practiced eye soon discovers when they are in need of water. Sub-irrigated soil is often deceiving to the eye, as the top is dryer than the bottom, but a little experience will soon enable any one to determine, by running the hand into the soil, when water is needed. It is generally safe to keep the surface of the soil quite dry, while the lower portions may be so wet that when pressed in the hand it will not fall apart, but will retain the shape given it by the hand when the pressure is removed. More water than this may be applied to lettuce plants, without injury, even to the extent of making the surface of the soil appear to be wet. By this method of watering there is less danger of over than underwatering, hence it is well to give water in abundance. This is especially true of lettuce, as it requires large quantities of water.

There is no need of sprinkling the foliage of lettuce plants frequently during growth. It may be well to sprinkle the plants once as soon as they are set in the beds, but it is not really essential, although they probably start to grow more quickly and surely than if sub-irrigated altogether. A slight wetting of the surface of the soil saves such a complete saturation as may be necessary otherwise, while the plants are small, and before the roots have penetrated to any considerable distance. To continue to water on the surface is not advisable, as it is not only a waste of time but compacts the soil, which involves extra labor in working it up again Contrary to the general belief, the plants are not benefited by having the foliage sprinkled, nor is it necessary to sprinkle the walks in order to introduce moisture into the air. These remarks refer to lettuce plants only, but so far as known might be applied to other vegetable crops.

As before stated, it is not known whether watering sparingly and frequently, or profusely and at long intervals, is the better plan; it appears to matter little which plan is followed, hence no rules can be laid down. It is possible to give sufficient water at the beginning to carry a crop of lettuce through, but we have not followed this practice, nor does it seem to be advisable to do so, for the quantity of water required varies

with the season and the size of the plants. The best plan is to give water as the plants seem to need it, and to be sure to give enough, as with lettuce the danger lies in withholding rather than in overwatering.

When lettuce is to be grown late in the spring, a hot bed, or a cold frame simply, answers better than a greenhouse, as the latter becomes too warm, while the beds are more easily ventilated. Moreover, a better use can be made of the greenhouse in growing tomatoes at this season of the year. It is not advisable, at any rate, to attempt to force lettuce in the greenhouse, in this latitude, later than the first of April. A bulletin on tomato culture under glass will be issued soon.

SUMMARY.

(1.) A water-tight bench bottom is necessary in sub-irrigation, and may be made of matched lumber, or of any rough lumber, the cracks being battened with lath, after which cement is spread over the bottom to the depth of half an inch. A better plan is to make the bench bottom of tile, with iron supports. A bed may be made on the ground also.

(2.) The irrigating tile may be laid lengthwise or crosswise the beds and the latter plan has been the more satisfactory. If long runs of tile are used there should be a slight fall of one or two inches to the hundred feet, and strips of tin should be inserted into the joints at intervals to check the too rapid flow of water to the lower end.

(3.) Sub-irrigation in the greenhouse grew out of an attempt to prevent lettuce rot, by watering below so as to avoid wetting the foliage.

(4.) Watering by sub-irrigation is more efficiently and cheaply done than by the ordinary method; sub-irrigated soil does not harden, but retains its original loose, friable condition, nor does it become mossy and water logged. Furthermore, plants are less liable to suffer from overwatering and disease by sub than by surface watering, and in consequence grow more vigorously.

(5.) These good effects are supposed to be largely due to the facts that sub-irrigated soil is always in a condition to allow the air to permeate it freely and that uniformity and constancy of the supply of moisture to the roots are assured by this method of watering.

(6.) The gain in weight of sub-irrigated lettuce over surface watered has been, in some cases, as high as 100 per cent., but in most of the experiments about 40 per cent. In one case the increase in the value of the crop was sufficient to pay the cost of the new bench bottoms, and in all cases the cost of reconstruction has been reimbursed the first season.

(7.) It is a fact that good head lettuce cannot be grown on heavy soil by surface watering, and the same is, in a measure, true of all varieties; but with sub-irrigation this kind of soil is not precluded, hence the method of watering greatly enlarges the possibilities of lettuce culture.

(8.) Local conditions should not be overlooked, such as soil and market requirements. It would be futile to attempt to follow Eastern methods in this section, because the conditions are different.

(9.) The head lettuces are grown in the East, but are not demanded in our markets, hence the Grand Rapids is more suitable here, as it can be grown more cheaply.

(10.) The practice in vogue in the East of making beds on the ground and of using a foot or more of soil, although the best plan there, is not necessarily so where sub-irrigation is practiced, as by this method six inches of soil is sufficient.

(11.) Lettuce flourishes best in the greenhouse from midwinter until spring, and is usually most in demand during that period, but late in spring it does better in beds out of doors, after which time the houses may be more profitably occupied with tomatoes.

(12.) The best plan of starting the small plants is in flats, and these are best watered by placing in shallow vats of water, so as to sub-irrigate.

(13.) The plants should be transplanted as soon as they show the second leaf, placing them 2 x 2 inches apart for Grand Rapids, and twice that distance for heading sorts; 6 x 7 inches for the former and 8 x 8 inches for the latter when planted in beds.

(14.) The plants should be kept growing from the start, but should not be forced in too high a temperature; 50 to 60 degrees by day and 40 to 50 by night being about right. A high temperature favors the development of lettuce rot.

(15.) Ventilation is important or rot will appear. The most critical time is in cloudy, cold weather, because it is then not easy to ventilate.

(16.) No rule can be given for watering, but when sub-irrigated the soil should appear to be rather dry on top, and wet enough below so that when pressed in the hand it will not fall apart when released, but retain the shape given it by the hand.

(17.) The plants may be sprinkled once when set in the bed, but after that it is not necessary and is a waste of time, nor is there any need of sprinkling the walks in order to introduce moisture into the air.