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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 40.

FARM DRAINAGE.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Soils,
January 31, 1899.

Sir: I have the honor to transmit herewith copy for a revised edition of Farmers' Bulletin No. 40, entitled Farm Drainage, by C. G. Elliott, C. E. This bulletin was originally submitted in 1896, but has now been revised and brought up to date, thereby increasing its usefulness for continued distribution.

Very respectfully,

Milton Whitney,
Chief.

Hon. James Wilson,
Secretary.

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FARM DRAINAGE.

Soil drainage is the removal, either naturally or by artificial means, of the surplus water from the soil; hence a drained soil is one which is moist but not saturated with water.

All soils used for the production of the plants most prized by the farmer, gardener, or fruit grower must possess, in addition to other necessary elements, a certain quantity of water, or they will not yield the largest possible returns to the cultivator. This water is usually termed moisture, and soils in which the proper proportion exists are commonly called dry soils to distinguish them from those which contain a surplus of water and are called wet soils. The farmer, therefore, in speaking of a dry soil does not mean one which is devoid of water, but one which contains the quantity of moisture best adapted to produce the most desirable growth of his plants, while the term "wet soil" indicates one that contains more water than is needed, which acts in such a way as to prevent plants from reaching perfection.

A perfectly dry soil is dead. It is worthless for producing plants, except those which derive their nutriment from the atmosphere alone. A soil which is completely saturated with water will produce nothing but aquatic plants, and hence is worthless for cereals and other valuable products.

The nutriment which plants take from the soil is in liquid form only, it having been prepared by chemical action brought about by the union of heat and moisture with the elements present. An excess of moisture reduces the temperature, excludes the air, and dilutes the plant food, thus retarding or entirely stopping the growth of the plant as effectually as is done when the soil is too dry.

TEXTURE OF SOILS AND ITS RELATION TO THEIR DRAINAGE.

Soil is composed of a large number of exceedingly small particles of various shapes which touch each other, or, more strictly speaking, have a film of water or of air between the contiguous parts. Experiments are being made to determine how fine these particles are and just how much empty space there is in a given volume of soil, but that is not material in this discussion. Suffice it to say that these particles vary in size in different soils. Those composed largely of sand have much larger particles than those in which stiff clay or fine loam predominates. As these particles can not lie together so as to form a solid, there is a large volume of empty space, which in an average soil equals one-half of its volume. By that law of physics known as surface tension, that is, the attraction which the surface of a solid has for a liquid, each particle of soil holds a film of water over its entire surface, and thus provides a supply of this material for the roots of the plant. When the quantity of water in the soil is greater than is required to supply that which is held by surface tension, the remaining space is filled, and the soil is said to be saturated. Fig. 1 shows these conditions and illustrates the difference between a drained and a saturated soil. If we provide an outlet for the water, the surplus will pass off by force of gravity, leaving only the film which is held by surface tension and which furnishes the desired moisture. Thus from 15 to 50 per cent of all the water which a soil will hold will not pass off as drainage, but will remain to contribute to the growth of plants and to aid further in the preparation of additional plant food.

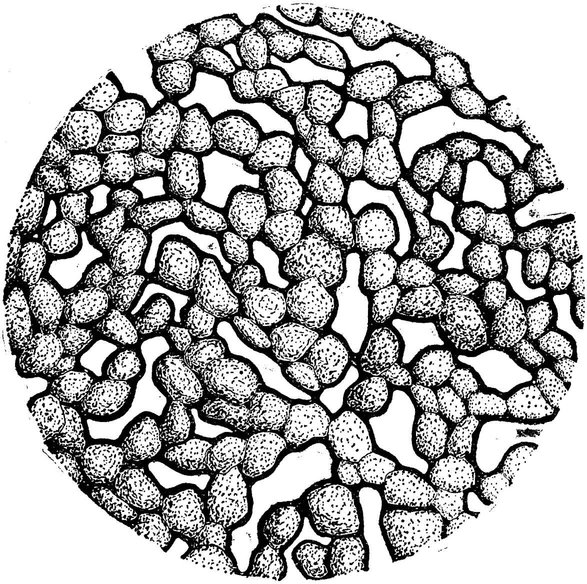

Fig. 1.—Section of moist soil showing film of water around the grains.

This necessary moisture moves through the soil, even against gravity, by the force of capillary attraction, or surface tension shown in the rise of liquids in small tubes and between surfaces of solids which are close together. This force tends to distribute and equalize moisture in the soil. Where the principal supply is above or in the surface layers, it is drawn downward; where it is below, it is drawn upward.

As before stated, about 50 per cent of the volume of ordinary soils is space, and is always filled with water, or air, or both. The individual spaces are larger or smaller according as the soil grains are more or less minute. A close clay soil and a very coarse sandy soil will illustrate the extreme differences. The fine grains present more surface in a given volume, and hence will retain the greater quantity of moisture. The coarser soils will permit a much freer percolation of water, and hence quicker drainage than fine ones, since the closeness of the particles offers an additional resistance to the passage of water by gravity through the soil.

It will be seen from this brief explanation that in well-watered localities drainage is the regulator of soil moisture, and as such is necessary in many soils.

NATURAL AND ARTIFICIAL DRAINAGE.

Some of the best drained soils are so by nature. They are underlaid with a stratum of material which gives free egress to surplus water, and are composed of elements which respond readily to the efforts of the cultivator. On the other hand, there are soils just as rich in natural fertility, but which are unproductive because, under all ordinary circumstances, they contain too much water. Their natural location is such that they are saturated beyond the point required for profitable plant growth. It is only when the rainfall reaches a minimum quantity and the climatic conditions are most favorable that such soils yield the desired harvest and a profitable return for the labor of the cultivator. Such soils should be artificially drained. This only will develop their fertility and make them profitable to their owners. Whether the excess of soil water comes from rainfall direct or from seepage of soils which occupy a higher level, the surplus must be removed before the soil will be in proper condition for plant growth.

SURFACE DRAINAGE AND UNDERDRAINAGE.

Surface drainage is the removal of water from the land before it enters the soil, or at least before it penetrates farther than the surface layer. This is effected by open surface channels. Underdrainage removes surplus water by taking it downward through the soil and away from it by means of natural or artificial channels within the soil. Sufficient surface drainage should be provided to insure the completion of the work of underdrainage. This principle should stand out clearly in drainage operations, viz, that all surplus water should be removed by passing it downward through the soil and not over its surface. The advantages of so doing may be briefly stated, as follows:

The surface soil is retained entire, instead of the finest and most fertile parts being carried off with every considerable rainfall.

Any manure or other fertilizer deposited upon the soil is carried into it with the water as it percolates downward from the surface, and so becomes thoroughly incorporated with the soil.

Rain water itself is a valuable fertilizer and solvent, enriching the soil by dissolving and preparing crude soil material for the nutrition of plant life.

The soil is prepared and is at all times in readiness during the growing season for the growth of plants, such growth not being hindered by stagnant water or saturated soil.

The frost goes out earlier in the spring, so that the planting season opens one or two weeks earlier than in the case of undrained soils.

In the case of stiff clays, the soil is made more porous, open, and friable, and roots penetrate deeper than they do into undrained soils.

The effects of drought are diminished, as has been found by experience, owing to the enlarged and deepened soil bed and to the perfect condition of the surface for preventing undue evaporation of moisture.

It aids in making new soil out of the unprepared elements, since it permits a freer entrance of frost, air, and atmospheric heat, which disintegrate soil material hitherto unavailable for use of plants.

LANDS REQUIRING DRAINAGE.

All farm crops, fruits, and garden productions require a drained soil, but this does not necessarily mean that they need artificial drainage. When, however, natural water courses are insufficient to remove the surface water, they must be improved by artificial means. Where the subsoil is close and permits the water to pass through it slowly or not at all, thereby keeping the soil saturated for several days after every rainfall, we must resort to artificial drainage. Soils known as "spouty," that is, soils kept saturated by springs or by water which percolates through from higher levels, should be relieved by underdrainage. Of course, it is understood that soils to be drained have natural fertility, or are capable of being profitably enriched. Some wet soils are so lacking in the elements of fertility that drainage will not improve them.

TILE-DRAINAGE.

The best method of underdrainage yet devised is tile-drainage, which consists in laying well-burned circular clay pipes, 1 foot long, in continuous lines through the soil so that any water which finds its way into the tiles will be carried by gravity to some lower point, thus conveying the surplus away from the soil. Water enters the line of tiles through the openings left between the ends, or "joints" as they are called. The ends of the tiles should be placed close together, in order to prevent the soil from entering, yet not so close as to prevent the entrance of water. The action of a tile drain in removing the surplus water from the soil is as follows: The drain being surrounded by soil the spaces of which are filled with free water, water flows by gravity through the crevices between the ends of the tiles and passes off more or less rapidly, according to the grade upon which the line is laid. Other water of the soil takes the place of that which was removed, the water of saturation gradually passing from the surface downward, that near the level of the drain being the last to pass off. Water moves downward and laterally toward the drain. The lateral distance to which the drain will relieve the soil of water is governed by the resistance which the soil particles offer to the flow of water between them. This process does not leave a soil without moisture, but one containing all the water held by surface tension. Neither does the drain remove water from points below the level of the drain.

In this process it is interesting to note that, while to begin with the soil is fully saturated, no stagnant water remains. There is a continuous movement, the upper water taking the place of the lower as it is removed.

In order to secure efficient drainage the separate lines of tile must be placed sufficiently near to each other for the effect of one line to reach that of the other, thereby bringing all the soil within the active range of the drains.

WHAT SHOULD GOVERN THE DISTANCE APART AND DEPTH OF UNDERDRAINS?

The answer to this question depends upon the character and general structure of the soil. Because a certain depth and distance apart has given satisfactory results in one locality and with one kind of soil, it does not follow, as is sometimes supposed, that the same treatment will give equally good results in soils of a different character. The readiness and rapidity with which soils drain depend upon the fineness and compactness of the soil particles composing them. If the material to be drained were coarse sand, a single drain might have an effect for several hundred feet on each side of it, whereas if it were close clay of certain kinds the effect of the drain would reach perhaps only 15 feet on each side. Hence it follows that only close observation will furnish the means of determining the lateral distance apart at which it is proper to place drains. Dig a hole in the ground when the soil is saturated and observe how rapidly the water fills it. Note the effect which any newly dug open ditch or natural drain has upon the adjacent soil. If these fill very slowly, the drains must be placed somewhat near, perhaps not more than 30 or 40 feet apart. On the other hand, drains may be placed 50, 80, 100, or even 200 feet apart in some soils, and the effect be all that is desired.

The thoroughness and rapidity of the drainage desired are also points to be taken into account in determining what distance the drains should be apart. Ordinary field crops will bear slower soil drainage than would be desirable for high-class gardening.

The depth at which it is profitable to place the drains is also contingent upon the character of soil treated, though it may be stated, as a general rule, that lateral drains should be 3 feet deep. There are, however, many soils which may be drained 4 feet deep. Orchards and fruit gardens should be drained to this depth, while there are soils underlaid with hardpan, containing in themselves no fertility, in which care should be taken to locate the drains as near as possible on the line separating the soil proper and the clay. If the soil is open, so that water percolates freely through it, the depth may be increased and the distance apart increased proportionally.

KIND OF TILES.

The tiles used should be circular in form, straight, and, above all, well burned. They need not be vitrified to be lasting, but whatever kind of clay is used in making them every particle should be completely burned; the tile is then indestructible in earth and water. But where exposed to long continued freezing and thawing, as at the outfalls, the best vitrified pipe should be used. After one has become familiar with the ware of a particular factory, the poorly burned tiles may be readily distinguished by their color and by their ring when struck with a piece of steel.

SIZE OF TILES TO BE USED.

The proper size of tiles to use in the construction of drains is a matter upon which there is great difference of opinion and accordingly of practice. It is doubtful if there is any part of the work requiring more careful consideration than this. An artificial system of drainage sometimes fails in removing the water, not because the tiles are too small, but because they are not located properly or not properly laid, or because the texture of the soil is such as to prevent the ready access of the water to the tiles.

There are several matters to be considered in determining the size of tiles that should be used, especially for mains to a drainage system: First, What depth of water per acre will it be necessary to remove from the land in a given time, say twenty-four hours, in order to secure the desired drainage? Second, How rapidly will the water be brought to the main drains? Third, What surface drainage does the tract have that will be available for carrying more than ordinary rain storms? Taking into account these contingencies, what should be the size of the main drains, considering the grade upon which it is proposed to lay them?

As to the first question, it may be answered that there are times during the growing season when the entire ordinary rainfall will be taken up by the soil. At other times, when the rainfall is frequent and heavy and the soil becomes filled with water, it may be necessary to remove a large part of what falls in twenty-four hours. There are times when the rainfall is so heavy that the water can not pass through the soil fast enough, even if the drains are sufficiently large to admit of it, but a part must run off the surface by its various depressions and channels, and these it is always well to provide.

If the main drains have the capacity to remove one-half inch in depth of water from the entire tract in twenty-four hours, they afford what may be regarded as good farm drainage; for even one-fourth or one-third of an inch in that time is the limit of the capacity of many of the drains on our well-improved alluvial soils. The soil is a great reservoir, and will hold from 25 to 40 per cent of its volume of water. In localities where no advantage can be taken of surface flow for relief in times of very heavy rainfall the mains should be so constructed as to carry off 1 inch in twenty-four hours.

For lateral drains no smaller than 3-inch tiles should be used, and for open soils, where the lines may be placed 100 feet or more apart, no smaller than 4-inch tiles should be used.

The following tables may be used to determine the number of acres which a tile of given diameter and per cent of grade will drain when used as an outlet. They are based on Kutter's formula, and are applicable to main drains, well laid, where the water is supplied to them by submains and laterals. Table 1 gives the discharge in cubic feet per second for sizes of tile-drains from 4 inches to 20 inches in diameter, computed on a grade of 1 per cent, or 1 foot per 100. Table 2 gives the square roots of grades from 0.04 foot per 100 feet to 1 foot per 100 feet.

TABLE 1.—*Discharge of tile from 4 inches to 20 inches in diameter on a grade of 1 foot per 100 feet.*

Diameter of tile in inches.	Discharge in cubic feet per second.	Diameter of tile in inches	Discharge in cubic feet per second.
4	0.16	10	2.05
5	.31	12	3.40
6	.49	15	6.29
7	.72	18	10.37
8	1.11	20	13.85
9	1.53		

TABLE 2.—*Grades per 100 feet, and their square roots.*

Grade per 100 feet in feet.	Grade in inches (approximated).	Square root of grade.	Grade per 100 feet in feet.	Grade in inches (approximated).	Square root of grade.
0.04	1/2	0.200	0.35	4 1/4	0.592
.05	5/8	.224	.40	4 3/4	.632
.06	3/4	.245	.45	5 3/8	.671
.07	13/16	.265	.50	6	.707
.08	7/8	.283	.55	6 5/8	.742
.09	1	.300	.60	7 1/8	.775.
.10	1 1/8	.316	.65	7 3/4	.806
.12	1 1/2	.346	.70	8 3/8	.837
.14	1 3/4	.374	.75	9	.866
.15	1 7/8	.387	.80	9 5/8	.894
.16	2	.400	.85	10 1/4	.922
.18	2 1/4	.424	.90	10 3/4	.949
.20	2 1/2	.447	.95	11 1/4	.975
.25	3	.500	1.00	12	1.000
.30	3 5/8	.548			

To determine the number of acres that a tile main of given size and grade will drain, multiply the discharge of the tiles, according to size, as given in Table 1, by the square root of the grade upon which it is proposed to lay the main, as found in Table 2. When it is desired that the main shall carry 1 inch in depth per acre in twenty-four hours, multiply this result by 24; if one-half inch, multiply by 48; if one fourth inch, multiply by 96.

Example: How many acres will a 12-inch main drain when laid upon a grade of 2 inches per 100 feet, using the half-inch standard.

From Table 1, a 12-inch tile on a 1 per cent grade is found to discharge 3.40 cubic feet per second. From Table 2, the square root of 0.16 foot, or 2 inches, is ascertained to be 0.40 foot; $3.40 \times 0.40 \times 48 = 65.28$ acres. The same laid on a grade of 3 inches per 100 feet = 81.6 acres. For the most of our open soils the one-fourth inch standard is what is used in practice, and is attended with good results. This is where drainage water is taken from the surface as distributed by means of lateral drains into the main, and not permitted to run over the surface until it accumulates in a few places, and thence find its way into the drain.

In addition to the use of the tables for determining the size of drains, good judgment must be used in the application of the results. The tract under consideration may have such surface or topography that the underdrains may be called upon to take the drainage of a much larger tract than if the land were nearly level. By reason of the surface slope and drainage, a main may be required to receive the drainage of 20 acres instead of 10 acres, as would appear at a casual glance. It is important to take into account also all the facilities for natural drainage when one undertakes to drain land by tiles. Too large tiles involve an expense without adequate return, while those which are too small may entail an annual loss that will soon equal the amount that was apparently saved in their purchase.

The proper adjustment of size to the grade upon which the lines are to be laid is important, both for economy and efficiency. Where large tracts are drained, some surface relief drains should also be provided against excessive rainfall in order to keep the expense of the main underdrains within the limits of paying returns. A few computations based upon the tables will show very clearly the comparative capacity of drains of a given size laid upon different grades.

HOW TO LOCATE DRAINS.

To begin with, there must be an outlet available for the system of underdrains which it is proposed to construct. This, as will readily be understood, is indispensable. A field or farm may sometimes be thoroughly drained by simply laying tiles in those parts which are uniformly too wet for profitable cultivation. This is on the theory that the other parts have sufficient natural drainage. In such cases main lines should be located in the course of natural surface flow, with due regard also to straight courses. Branch lines should follow the same general law. This does not, of course, mean that the curves and crooks which are always found in natural depressions should be followed; straight courses joined by curves should mark the lines for drains.

Land which requires drainage always lies in natural districts of greater or less size, each district or section having one point to which all the drainage must finally come. These general districts are again divided into subdistricts, each having its outlet within the limits of the general district. The boundaries of these sections should first be determined and the plans so made that when the drainage work is completed the entire tract will have been provided for. A failure to do this is a fruitful source of disappointment in the drainage work. Locate the main drain in the natural depression, with submains at such points as will furnish outlets for tributary sections. These are the arteries, as it were, of the whole system. This work may be carried out in two different ways. The first is to locate branch lines so as to reach those parts of the tract which seem to require drainage, such as ponds, swales, sags, etc., without special regard to systematic work. This is called random field drainage. The second is to supplement the primary network by constructing laterals parallel to each other at a uniform and equal distance apart, according to the requirements of the particular soil, on the theory that every part of the field requires equal drainage. Fig. 2 shows a tract of land in which both these plans are illustrated. The west side of the tract is uniformly level and has parallel drains equal distances apart, while the east side has a more broken surface, and hence the first-named plan is used. This is a map of a farm with drains constructed as shown, and illustrates nearly all the methods that may be used in laying out tile drains. The drains are systematically numbered and the sizes of tiles shown, as well as the length of each line from the outlet to any branch or to the end of any line. The length is given in stations of 100 feet and decimals. For example, 3.15 means 3 stations and $\frac{15}{100}$ of a station, or simply 315 feet.

The most economical system for thorough drainage is that of parallel lines of a good length. This will be readily acknowledged from the fact that wherever one drain joins another the tract in the vicinity of the junction has two drains acting upon it instead of one; in other words, it is doubly drained. The laterals should, as a rule, be laid up and down the slope, and not across it, as advocated by many. The method of locating drains on the west side of the field, shown in fig. 2, is to avoid so many outlets into the open ditch. It will doubtless seem incredible to those who find it necessary to place drains only 40 feet apart that other soils may be drained as thoroughly with parallel lines 100, or even 200, feet apart. In the latter case, however, the drains must be not less than 4 or 5 inches in diameter.

SURVEYS AND GRADES.

Whatever may be said to the contrary, it remains a fact that in order to get the best results in a system of drainage, the work should be laid out with a leveling instrument and executed in accordance therewith. No one can be relied upon to guess a grade correctly, nor can anyone arrange a system of grades with economy and at the same time get the best possible work out of the system without first knowing the facts as determined by the level in the hands of one who is able to use it. The drainage engineer will stake out the lines, adjust the grades, and put the work in such shape that it can be executed with precision, either by contract or day labor. The results of the work can be predicted

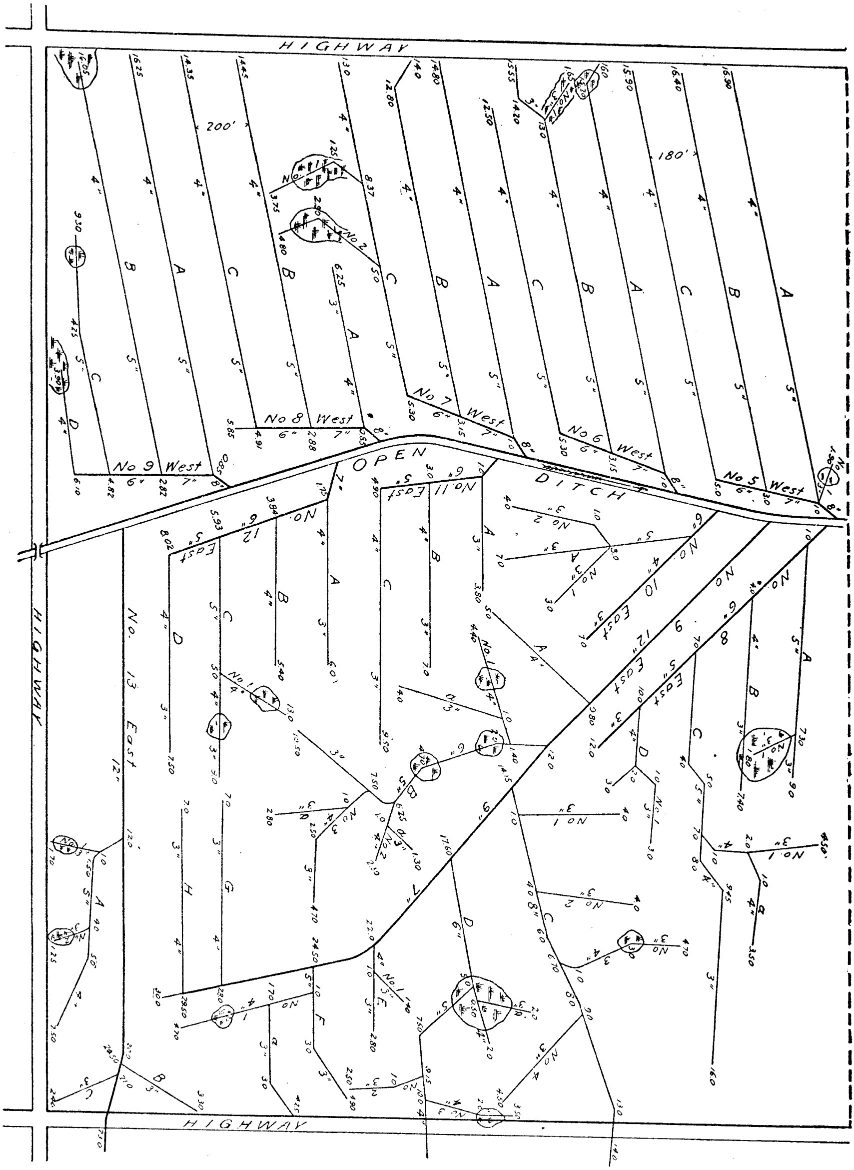

FIG. 2.—Diagram showing location of tile drains on a farm with open soil. (These drains have been in successful operation for seven years.)

with reasonable certainty before a ditch is opened. The drainage engineer, with the aid of the farmer who is familiar with the soil, can plan and lay out the work to far greater advantage than the inexperienced man. The farmer or superintendent can then give his attention to the execution of the work, and insist on having it done according to plans and surveys, without the misgiving that it may be entirely wrong. Where there are large tracts of level land, or of land so nearly level that it is only by the most accurate work with instruments that it can be drained successfully, the services of an engineer are indispensable.

The light grades upon which lines of tile may be laid with satisfactory results are a surprise to many; indeed, they were regarded as entirely impracticable until the experience of recent years proved the contrary. Lines of draintiles laid on a grade as low as one-half inch per 100 feet will perform drainage successfully, provided the lines are not too long, while drains laid on grades of from 1 to 2 inches per 100 feet may be counted by the hundreds of miles and their successful operation attested by thousands of acres of cultivated lands. It is not difficult to impress upon the mind of anyone who will give the matter attention the fact that such work must be laid out with accuracy and executed with thoroughness and skill. It should be observed in this connection that the fact that a drain has a good grade should not be made an excuse for careless and inaccurate work, though it is conceded that the consequences would be less serious than where the grade was but slight.

The drainage and improvement of land of this description returns such large profits that the best method of doing the work, being applicable to tile-drainage in general, will be briefly outlined.

DIGGING AND GRADING THE TRENCH.

The trench should be started on the surface by a line and should be clean-cut and straight. Any crook made at the surface will be greater when the bottom is reached. If a survey has been made, the line should be drawn about 8 inches to one side of and parallel with the line of grade stakes. It is assumed that these stakes have been set on a true line, 50 or 100 feet apart, and that cuts from the top of each grade stake to the grade line of the ditch have been furnished to the workman, or have been marked upon the guides which denote the position of the grade stakes.

The digging tools which are necessary in alluvial soils are as follows: A ditching spade with blade 18 or 20 inches long, a round-pointed shovel with long handle, and a grading scoop of the "pull" pattern. In light, mucky soils a muck spade, which is a three-tined fork with a steel cutting edge like a spade, can be used with profit. Where the clay is hard or stony, a pick and iron bar will be necessary. Straight ditches and neat work should be insisted upon, since the labor required is no greater than in digging crooked and ragged ones, and a drain in a true line is more efficient than one which has short, irregular crooks. Where it is necessary to change the direction of the line, it should be done by an easy curve. When a lateral drain joins another, it should form an angle of about 30 degrees with it.

The most essential thing about a trench for a tile drain is the finish and grade of the bottom. When only light grades are available, the lines should be staked out and leveled as before indicated. The writer speaks advisedly upon this point, for he knows of so many failures in the action of tile drains through neglect of this kind that he makes no exceptions to the statement nor offers any apology for it. Many farmers have drained successfully where the fall was 3 feet or more per 100 feet, because it was almost impossible to grade the line so that it did not have fall and because the fields were small. Such men frequently advise freely against having the work laid out by an engineer and the grades carefully computed.

It does not follow, however, that because the work is carefully laid out it is a guaranty of success in itself. The work must be properly carried out, and that requires a knowledge of how to do it. It is claimed that water is the best possible guide for grading the bottom; it is true that where water will flow in a trench it will flow in the drain after the tiles are placed. But much of the drainage work on level land must be done when there is no water in the soil to guide the workman. Even where there is water, long lines on light grades can not be carried to distant fields with any assurance that the desired grade and depth will be secured.

GRADING FROM A SURVEY.

The simplest and most expeditious way to grade a ditch from a survey is by the "target" or crossbar plan, as illustrated by fig. 3. It

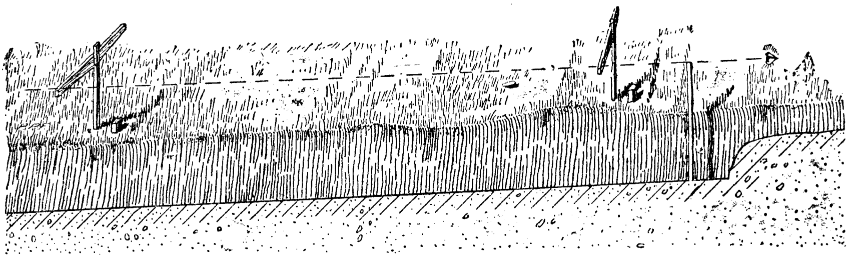

FIG. 3.—Grading the bottom of the ditch by targets.

assumes that the line has been staked out and that grade stakes have been set at a distance of from 50 to 100 feet apart, and the depth of the ditch given at each stake. It is necessary to dig the ditch to the depth called for at the stakes and to connect those points by a true line.

The target consists of a rod of five-eighths inch iron, 4 feet long, pointed at one end, and a crossbar of wood about 3½ feet long. The bar is furnished at the middle with a clamp and thumb nut, so that it may be made to slide up and down on the rod and be clamped firmly at any desired position. The clamp should be so made that the bar may be tilted and set horizontal, even when the standard is not in a vertical position. An outfit consists of three targets and a light sighting rod. At least two of these targets must be set, one at each of two different grade stakes, and so set that a line of sight over the upper edges of the bars will be parallel to the bottom of the ditch, as indicated by the depth figures which have been furnished by the engineer. A convenient length for a sighting rod for farm drains is 5 feet.

To set a target.—Set the iron standard firmly in the ground near a grade stake. Measure off on the "sight rod" the depth of the ditch at this stake, and make a light mark upon the rod. Set the opposite end of the rod upon the grade stake, and slide the target on its standard until the top of the bar is even with the mark before made. Clamp the target at the center, and tilt the bar so that it will be horizontal. The bar should extend over the center of the ditch, and may be leveled with a small pocket level. In the same manner set another target at a second grade stake. The tops of the targets are now placed at just the length of the sight rod above the grade line of the ditch. One bar should be painted red and the other white, for convenience in sighting over them. A third target should be set at a third stake, or in line with the other two, as a check or in turning a curve.

Method of using.—Begin at the outlet of the drain, or at its junction with the main, and dig the trench to such a depth that it can be finished at one spading, as it is called. Set the targets as before directed at stakes 0 and 1. Set the third target at some point below stake 0 and in line. The tops of the three bars are now on a line, and the line is parallel with the bottom of the proposed ditch. Begin at the lower end and take out the last or bottom spading to the proper depth, as near as may be judged, working backward, taking care not to dig too deep. When 4 feet in length, or thereabouts, have been excavated, use the cleaning hoe to clean out the crumbs and to dress the bottom. Test the finished ditch by holding the sighting rod vertically in the ditch at the point to be tested. If it lines with the top of the targets or crossbars, the bottom is correct; if it does not, dress with the cleaner until it does. It is then finished and ready for the tiles. Proceed in this way, finishing as you go. In setting another target pull up the lower one and set it at the next stake, testing it for line by the two already in position. The bottom should be fitted so that the tiles which are to be used will fit closely in the prepared bed. (See fig. 4.)

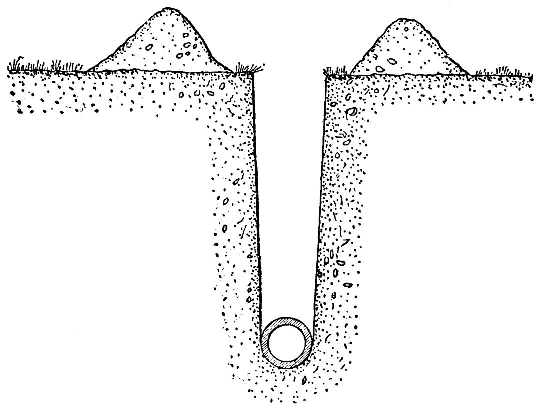

Fig. 4.—Section of trench with tile in place.

This method of digging and grading a ditch is simple and correct. The tiles can be kept laid in the finished ditch with no fear that they may not be right. If the tiles to be laid are large, say 10 inches and upward, the shovel must be used in cleaning and preparing the bottom.

LAYING THE TILES.

After the bed is prepared, the tiles should be laid from the outlet upward, the workman walking backward in the ditch and laying the tiles in front of him, turning them until they fit closely on the top. The value of starting the ditch straight, and keeping it so, will now be appreciated. In making curves, the straight tiles can be used by turning them until they fit one to the other, or in case a crack is necessarily left it should be covered with a piece of broken tile. Junction tiles should be set where laterals are to enter.

However close the joints may be made, there will always be sufficient space for the entrance of water. In case the bottom of the trench is fine sand or silt filled with water, there may be some danger of the material passing through the joints into the tiles. To prevent this, put clay upon the joints, or wrap each joint with a strip of tarred building paper. In ordinary clay or loam there need be no fear entertained that the tiles will fill with solid material if they have been properly laid. Let the same care be exercised in the construction of the entire system of tile drains, and its successful operation can be assured.

FILLING THE TRENCHES.

Enough earth should be thrown upon the tiles after they are laid to secure them in their position. This had better be done by a careful workman, who should see that moist earth is thrown around and over the tiles in such a way that they will not be moved by any subsequent filling. After this is done, the filling may be completed in the most convenient and expeditious manner. Where the land is cultivated, the ditches can be filled rapidly with a plow pulled by a team on each side of the ditch. The evener used should be 16 feet long. The excavated earth, it has been assumed, has been thrown in about equal quantities on each side of the ditch. In meadow or sod land a V-shaped scraper with the point behind, made for the purpose, can be used without disturbing the turf. In order to use either of these methods satisfactorily the banks should be somewhat dry, or sufficiently so, that the earth will fall apart when moved, instead of sticking together in a gummy mass.

It may be said in this connection that land should be cultivated the next year or two after being cut up with drains, because the earth is loose and continues to settle for a year, and this prevents grass from taking quick and permanent root. This is not the case with cultivated crops, as the most luxuriant growth may usually be found directly over the drains.

ACTION TO BE EXPECTED FROM UNDERDRAINAGE.

After heavy rains the surface usually begins to dry off first directly over the drain, the drying process extending on either side until the limit of the action of the drain is reached. This limit, as previously explained, will depend upon the closeness and structure of the soil particles.

These physical characteristics of the soil also affect in a remarkable degree the quickness of the action of drains, so that their effect as regards both time and extent varies greatly with the kind of soil acted upon; nevertheless, there are but few soils which will not respond to underdrainage if treated properly.

COST AND PROFIT OF TILE-DRAINAGE.

The ultimate question that must be answered in regard to drainage is, Will it pay? The agriculturist can usually answer that question if he can ascertain what the cost of the work will be. From what has been said regarding the necessity of varying the distance between drains to accomplish the same work in different classes of soils, it will be seen that the cost must necessarily vary greatly; the price of labor and material in different sections of the country is also subject to constant change. Those farms which consist of a part possessing natural drainage and a part requiring artificial drainage may be improved at a cost of from $6 to $8 per acre on the entire farm, where the outlets are provided for by nature. The improvement in this case consists in draining out the wet land and fitting it for profitable cultivation.

On others which require drains at a uniform distance of, say, 100 feet the cost will be $14 per acre, while on those lands requiring drains 33 feet apart the cost will be $22 to $25 per acre. These prices will vary, of course, according to the price of material and labor. The profit derived from draining wet land is quite apparent when we consider the fact that the same labor that is bestowed upon undrained land will produce from 20 to 50 per cent greater yield of cereals where the land is drained. As a rule, lands to be drained should have a large supply of fertility, drainage being the only thing needed to make them productive. It has, however, been found by experience that soils which require artificial fertilizing frequently become very productive when drained, since the fertilizers which are applied are enabled, by the effect of drainage upon the soil, to bring into use natural resources hitherto hidden and unavailable.

The writer has known of many thousands of acres of land that have been drained with greater or less thoroughness, and has never known of one instance in which the money so spent did not pay a large return on the investment. An annual profit of 25 per cent is not at all uncommon. The question should be looked at in the following way: If the farmer owns his land, he must pay the taxes, keep up the improvements, and procure the necessary help and implements for cultivating it. If there is land which he cultivates at a disadvantage because it is too wet to yield a full crop, and possibly yields none at all, proper drainage will cause this land to yield a full crop without the expenditure of any additional labor, seed, or capital, and the entire increase may properly be regarded as the profit of drainage. A few examples which have come under the writer's personal observation will help to emphasize these general statements.

A 20-acre field which usually yielded only 25 bushels of corn per acre was tile-drained at a cost of $200, or $10 per acre. The yield after drainage was not less than 60 bushels of corn per acre, and the yield of other crops in the rotation was in proportion. This gain of 35 bushels, at 30 cents per bushel, the selling price of corn at that time, paid for the entire cost of the drainage the first year.

A pond, previously waste land, was drained at a cost of $8 per acre. It was broken and sown to millet, and the first crop paid the expense of underdrainage. A farm of 160 acres situated in an Illinois drainage district was taxed $5 per acre for the general outlet. It was bought for $30, subject to the tax for $5, costing the purchaser $35 an acre. Tile-drainage and improvements cost $15 an acre, making the land cost $50 per acre. This farm was rented, and yielded the owner a rental of $5 per acre for four successive years, or 10 per cent on the entire investment. He was then offered $80 per acre for the farm and refused it.

It is a well-recognized fact that no practical gardener or fruit grower attempts to practice intensive cultivation on land which is not thoroughly drained, either naturally or by tile-drainage. It would be easy to multiply examples of the profits which accrue from the practice of soil drainage, not only to the farmer who drains his land and cultivates it after it is drained, but also to the capitalist who purchases land which is comparatively worthless without drainage, and then drains it as an investment.

What has been said, however, will be sufficient to indicate that nothing brings a surer return for money invested than does the drainage of rich soils.

OPEN DRAINS.

We have considered underdrainage as that drainage which directly affects the soil and puts it in the proper condition for plant production. We have assumed that sufficient natural water courses or artificial channels exist to carry off the water discharged by the system of underdrains. It is often the case, however, that the outlet channels must be provided before a system of underdrains can be constructed. This is always the condition of large tracts of level land. Such tracts must be cut up into sections or districts by large open ditches in order that tile drains may be laid in every part without necessitating the use of mains too large and costly to be profitable. While these open ditches are not desirable in themselves, since the land they occupy can not be used for any other purpose, and moreover they often divide land into tracts of inconvenient shape, yet they are necessary to every system of underdrainage. They should be located with care, following the course of natural drainage as near as may be, with due regard to straight courses. When these outlet ditches are located on land belonging to one individual, he has merely to construct them as in his judgment is best, and pay the cost of the work. But in all large tracts in which a greater or less number of landowners are involved, open ditches must be constructed by the cooperation of all parties benefited. A method of doing this is, in several States of the Union, provided for by statute. Outlets for the drainage of tracts from a few hundreds up to many thousands of acres have been provided for in this way, each owner within the district paying a share of the expense of such work proportionate to the benefit he derives. When these main channels have been made, it is intended that each owner shall be provided with an outlet for his drainage and that all subsequent drainage of his own land will be done at his own expense, without in any way infringing upon the rights of others, while the public drains will be controlled by the proper officers as provided by law.

PROPORTIONING THE COST.

After the course of the open ditches has been determined upon and an estimate of the cost made, a task of no little difficulty is to assess the cost of the same on the various tracts of land to be benefited. The principle recognized by all State laws in assessing the cost of work is that each tract of land should be taxed in proportion to the benefit to be derived.

Questions relating to the proportion that each one should pay when cooperative drainage is undertaken force themselves upon everyone who holds lands which will be affected by the work. Hence the consideration of the matter which is given in this connection. It will readily be seen by anyone giving the subject close attention that there are many phases of the problem which must be taken into account in adjusting the cost of work to benefits derived. The following are the prominent principles that must be borne in mind in determining benefits which will be derived by each landowner in the construction of common outlets by artificial means:

Each owner of land is entitled to all the natural drainage he has by right of ownership. If his land is so situated that he has sufficient outlet ditches, creeks, or channels provided by nature for the drainage of his land, he should not be called upon to assist his neighbor adjoining him in securing drainage. Land which has natural drainage facilities bears a higher price than a tract which is not favored in that way. Each landowner may drain his land as he chooses, provided he does it within the boundaries of his own possessions. If a tract of land is wet and practically useless for agricultural purposes, it should be taxed higher for drainage than land which is by nature better drained. Land which is distant from the main outlet channel should be taxed less for the same improvement than the tract alongside, unless a submain is constructed for its benefit, in which case the cost of said submain should be proportioned among the tracts benefited and added to the tax for the main as the total tax for that tract. The natural drainage of all tracts being the same, the land at the head end of the ditch should be taxed higher than that near the outlet, which is supposed to be some natural channel. With this in mind, there should be a gradation in the scale of assessment from the head end toward the outlet of the ditch. This is on the theory that if the owner of land farthest from a natural outlet desired drainage and was obliged to secure it at his own expense it would cost him much more than if his land were nearer to the outlet provided by nature. In short, the degree of natural drainage which a tract of land has and the distance which that tract is from both natural and artificial outlet, together with the measure of the completeness of the outlet afforded, are the main elements which should enter into the division of the cost of mains for agricultural drainage.

CLASSIFICATION FOR ASSESSMENT PURPOSES.

While there may be various plans for finding the share of the cost of an outlet that should be charged to each tract of land, the writer believes that the method by classification of land in accordance with the foregoing general principles, if done with good judgment, will proportion the cost equitably.

To put these principles into practice, select that tract of land in the district which will receive the greatest benefit, all things considered, and mark it 100. Compare all other tracts with this and mark them 40, or 80, or whatever number will express their relation to the standard 100. Each landowner may have several different classifications on his own tract. The number of acres in each class should be indicated and each tract given its proper rank with reference to the standard. Very careful consideration should be given to this part of the work, for upon this classification depends the justice and correctness of the assessments. If it is just and equitable, the amounts assessed against each tract of land will be right and fair.

To find the proportion of the cost of the work that each tract should pay, proceed as follows:

Multiply the number of acres in each tract by its classification mark. Divide the total estimated cost by the sum of these products; this will give a common ratio number. Multiply each of the above-named products by the ratio, and the result will be the amount that each of the respective tracts of land should be assessed. The following example will make the method plain:

Owner.	Number of acres.	Classification.	Product.	Ratio.	Assesments.
A......	50	40	2,000	.05263	$105.26
A......	20	60	1,200	....	63.16
B......	25	90	2,250	....	118.42
C......	40	70	2,800	....	147.36
D......	50	100	5,000	....	263.15
E......	30	10	300	....	15.79
E......	20	60	1,200	....	63.16
F......	40	70	2,800	....	147.36
F......	40	30	1,200	....	63.16
G......	100	90	9,000	....	473.67
H......	45	80	3,600	....	189.47
	460	....	31,350	....	1,649.96

Total estimated cost, $1,650; $1,650 divided by 31,350=.05263=ratio.

Explanation: The total estimated expense of the drainage outlet for a tract of 460 acres is $1,650. The tract which will be benefited most is one of 50 acres, owned by D, which is accordingly marked 100. Other tracts are classified with reference to this and marked accordingly. As before remarked, the important point is just here, in making the comparison correct. Besides being listed, as in the above table, these tracts should be described, and also be shown on a map, which should give their location with reference to the ditch.

Multiplying the number of acres in each tract by its classification mark, according to rule given, we have the products given in column 4. Dividing the estimated cost by the sum of these products, we obtain 0.05263 as the ratio. Multiplying each product by this ratio, we have the results shown in the assessment column, or the share of the expense which should be assessed to each tract.

Should there be branches or subdistricts, each should be classified in the same way, and the sums which appear against each tract for main and for sub districts will represent the total assessment. It is evident that each sub or branch should be paid for by the area benefited, and that acreage not benefited thereby should not participate in the expense. It will be seen that the matter of apportioning the cost in cooperative drainage depends upon correct knowledge of the benefits of drainage, coupled with unbiased good judgment.

The principles and methods herein outlined are only suggestive, but to those who have given the matter even a cursory consideration it will suggest a plan which will make it possible under State laws, or by mutual agreement, to secure necessary drainage outlets, where needed, at an expense which will be reasonably equitable to all.

CONSTRUCTION OF OPEN DITCHES.

Where a farm ditch has insufficient capacity as an outlet for the system of tile-drainage which it is desired to construct, it should be enlarged, or if there is no ditch some natural depression or water course should be straightened and enlarged until it has the necessary depth and width. The depth of such ditches should ordinarily be not less than 6 feet, with a width on the bottom of 4 feet, where the grade is 1 foot to a thousand, or less. If, however, the grade is much greater, say 3 inches or more per hundred feet, the bottom may be made as narrow as desired.

The side slopes in loam and clay soils may be made at an angle of 45 degrees, or what is called a slope of 1 to 1. Where the soil is loose and sandy, the slope must be 2 feet horizontal to 1 foot vertical, called a slope of 2 to 1. Ditches made with teams and scrapers can not be made profitably with slopes less than 2 to 1.

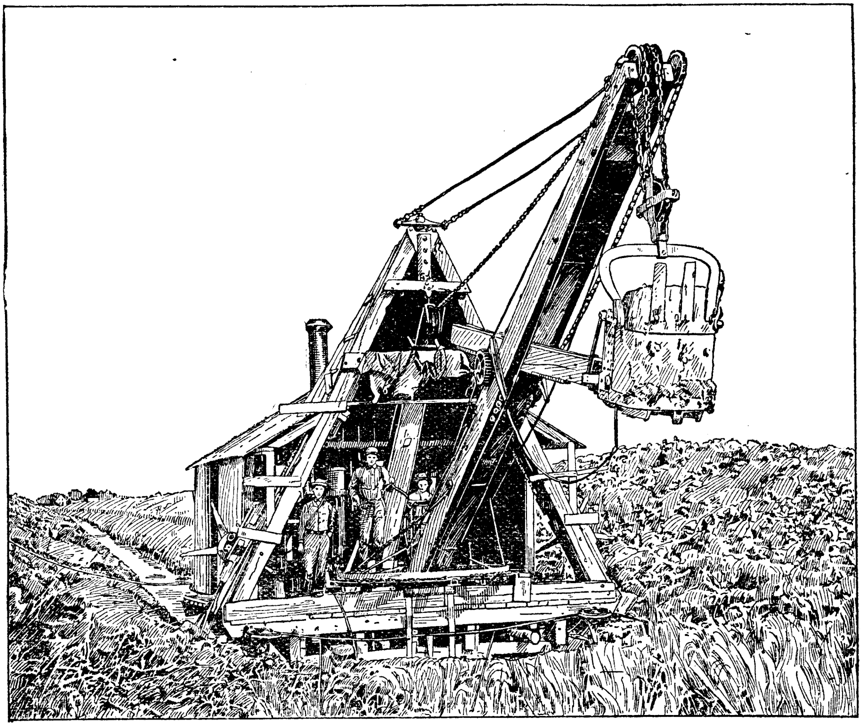

Fig. 5.—Drag-boat steam dredge, with finished ditch in the rear.

In the construction of artificial channels for the purpose of reclaiming large areas of level land there is no other method so satisfactory as that in which the steam dredge is used. These dredges are constructed for such purposes, and are of two different types.

One begins operations at the upper end of the channel and works toward the outlet. There must be sufficient water in the ditch to float the boat which carries the engine and excavating machinery. The excavated earth is deposited on each side of the ditch at a distance of from 6 to 12 feet from the edge of the channel. This type of dredge is adapted to the larger channels, from 18 feet to 60 feet wide, and as deep as desired.

The other type of steam dredge will make ditches as narrow as 4 feet on the bottom, and as wide as 10 feet, with side slopes of 45 degrees, and with depths ranging from 4 feet to 9 feet. This machine is placed at the outlet of the proposed ditch, and is pulled upgrade by means of a drum which winds up a cable which has been anchored in advance of the machine. No water is required in the ditch in order to operate it. It excavates the ditch to its full depth and grade, and completes the work from the outlet toward the source.

A cut of this type of a steam dredge is herein shown (fig. 5), with the excavated ditch in the rear. Either of these types of steam dredges can excavate the larger and longer channels in clay and loam soils at less cost than can be done by any other method.

It has been found by experience that ditches in such soils may be constructed with nearly vertical sides, or at most with no greater slope than 1 to 1, and that if the grade is 1 inch per 100 feet the ditches will be self-cleaning. The larger ones are very satisfactory with one-half this grade. The sides of the ditches do not retain their shape as cut, but in a few years take the shape shown by the dotted line in fig. 6. This is general, since the particular shape will vary with the depth of the ditch and the height to which the water flows in times of freshets.

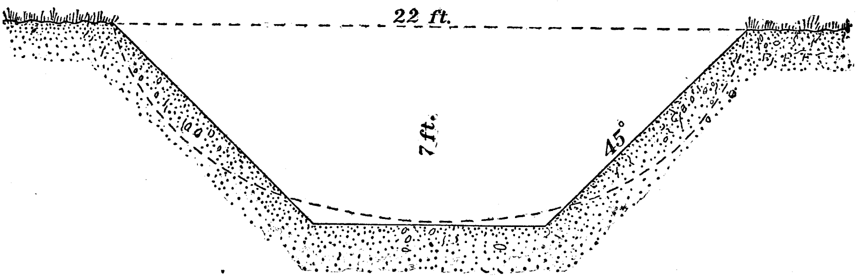

FIG. 6.—Section of open ditch with side slopes of 1 to 1. (The dotted line shows the general form which the ditch will take after being in use a few years.)

The excavated earth, which, of course, lies in unsightly masses along the ditch when the work is finished, will, after weathering through one winter, assume a much less formidable shape, and can in a year or two be worked down with plow and scraper until the land can be cultivated near to the banks of the ditch. It is always well, however, to keep a strip on each side and contiguous to the ditch in grass, in order to prevent the banks from crumbling and to keep the adjoining cultivated soil from being washed into the ditch in times of sudden and violent freshets.

The dredge has been mentioned as solving the large ditch problem for those wet and mucky soils where large deep ditches are required. Where the ground is dry, there are several other methods of making them, which need not be mentioned here.

The ultimate object to be sought is the thorough tile-drainage of all land which is not sufficiently underdrained by nature. As a large amount of preparatory work is required in building a railroad in order to secure a place on which to lay two steel rails properly, so in drainage the open ditches, the trenches, and all preparatory work is for the sole purpose of laying lines of tile in the soil in such a way as to take away the surplus water, as explained in the foregoing pages.

The importance of this work merits the care enjoined in carrying out the details, since drainage is a permanent improvement, and if the work is well done will need no repairs or reconstruction, but will yield an ample annual return as long as the soil is properly cultivated.

The following table gives the size of tiles, when laid at different grades, required to carry off one fourth inch of water in twenty-four hours. If it is desired to remove twice the above amount of water in twenty-four hours, multiply the acres to be drained by 2; if three times the amount, by 3, etc. Then look in the column having the desired grade for the number of acres corresponding most nearly to the acres you wish to drain when multiplied by 2, 3, or 4, as the case may be. The corresponding figures in the first column will be the diameter of tile required.

Acres from which one-fourth inch of water will be removed in twenty-four hours by tiles of different diameters and with different grades when used as outlets.

Diameter of tile.	Grade per 100 feet in decimals of feet.									
	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.15	0.20
Inches.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
4	3.1	3.4	3.8	4.1	4.3	4.6	4.8	5.3	5.9	6.9
5	6	6.7	7.3	7.9	8.4	8.9	9.4	10.3	11.5	13.3
6	9.4	10.5	11.5	12.5	13.3	14.1	14.9	16.3	18.2	21
7	13.8	15.5	16.9	18.3	19.6	20.7	21.8	23.9	26.8	30.9
8	21.3	23.9	26.1	28.2	30.2	32	33.7	36.9	41.2	47.6
9	29.4	32.9	36	38.9	41.6	44.1	46.4	50.8	56.8	65.7
10	39.4	44.1	48.2	52.2	55.7	59	62.2	68.1	76.4	88
12	65.3	73.1	80	86.5	92.4	97.9	103.1	112.9	126.3	145.9
15	120.8	135.2	147.9	160	170.9	181.2	190.8	208.9	233.6	269.9
18	199.1	222.9	243.9	263.7	281.7	298.6	314.6	344.4	385.2	444.9
20	265.9	297.8	325.7	352.5	376.3	398.9	421.9	460	514.7	594.3
Grade in inches (approximated)	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	1	$1\frac{3}{16}$	$1\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{3}{8}$

Diameter of tile.	Grade per 100 feet in decimals of feet.								
	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.
Inches.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
4	7.7	8.4	9.7	10.9	11.9	12.8	13.7	14.6	15.4
5	14.9	16.3	18.8	21	23.1	24.7	26.6	28.2	29.8
6	23.5	25.8	29.7	33.3	36.5	39.4	42.1	44.6	47
7	34.6	37.9	43.7	48.9	53.6	57.8	61.8	65.6	69.1
8	53.3	58.4	67.3	75.3	82.6	89.8	95.3	101.1	106.6
9	73.4	80.5	92.8	103.8	113.8	122.9	131.3	139.4	146.9
10	98.4	107.8	124.4	139.1	152.5	164.7	175.9	186.8	196.8
12	163.2	178.9	206.3	220.7	252.9	273.2	291.8	309.7	326.4
15	301.9	330.9	381.6	426.9	468	505.4	539.8	573	603.8
18	497.7	545.5	629.1	703.7	771.4	833.2	889.8	944.8	995.5
20	664.8	728.6	840.3	940	1,030.4	1,112.9	1,188.7	1,261.8	1,329.6
Grade in inches (approximated)	3	$3\frac{5}{8}$	$4\frac{3}{4}$	6	$7\frac{1}{4}$	$8\frac{1}{2}$	$9\frac{1}{2}$	$10\frac{3}{4}$	12

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