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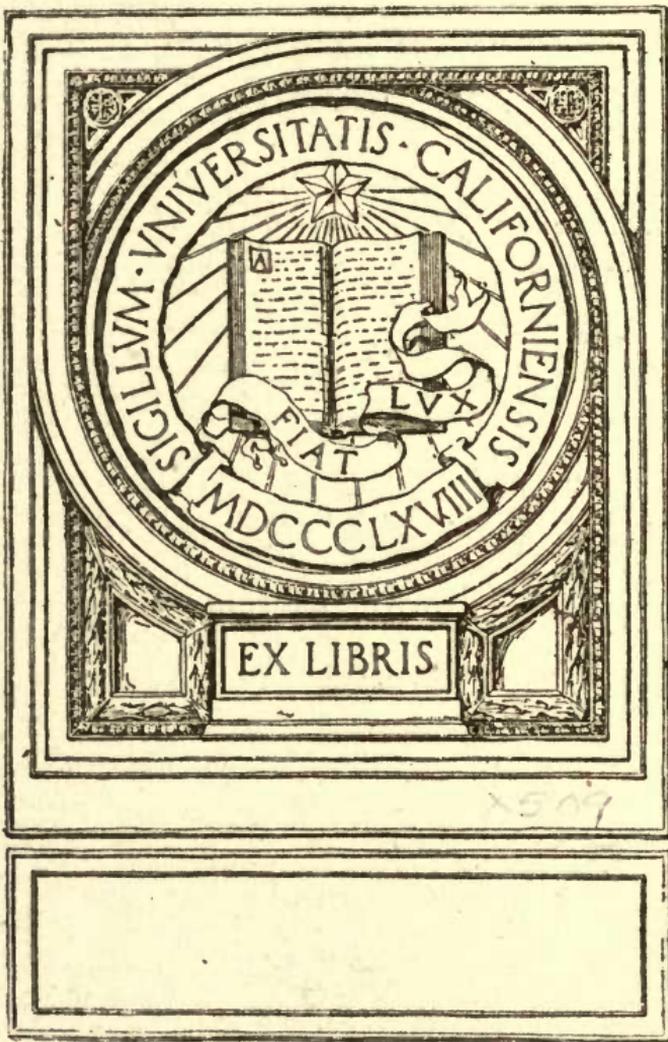


TEXT-BOOK
OF LAND
DRAINAGE

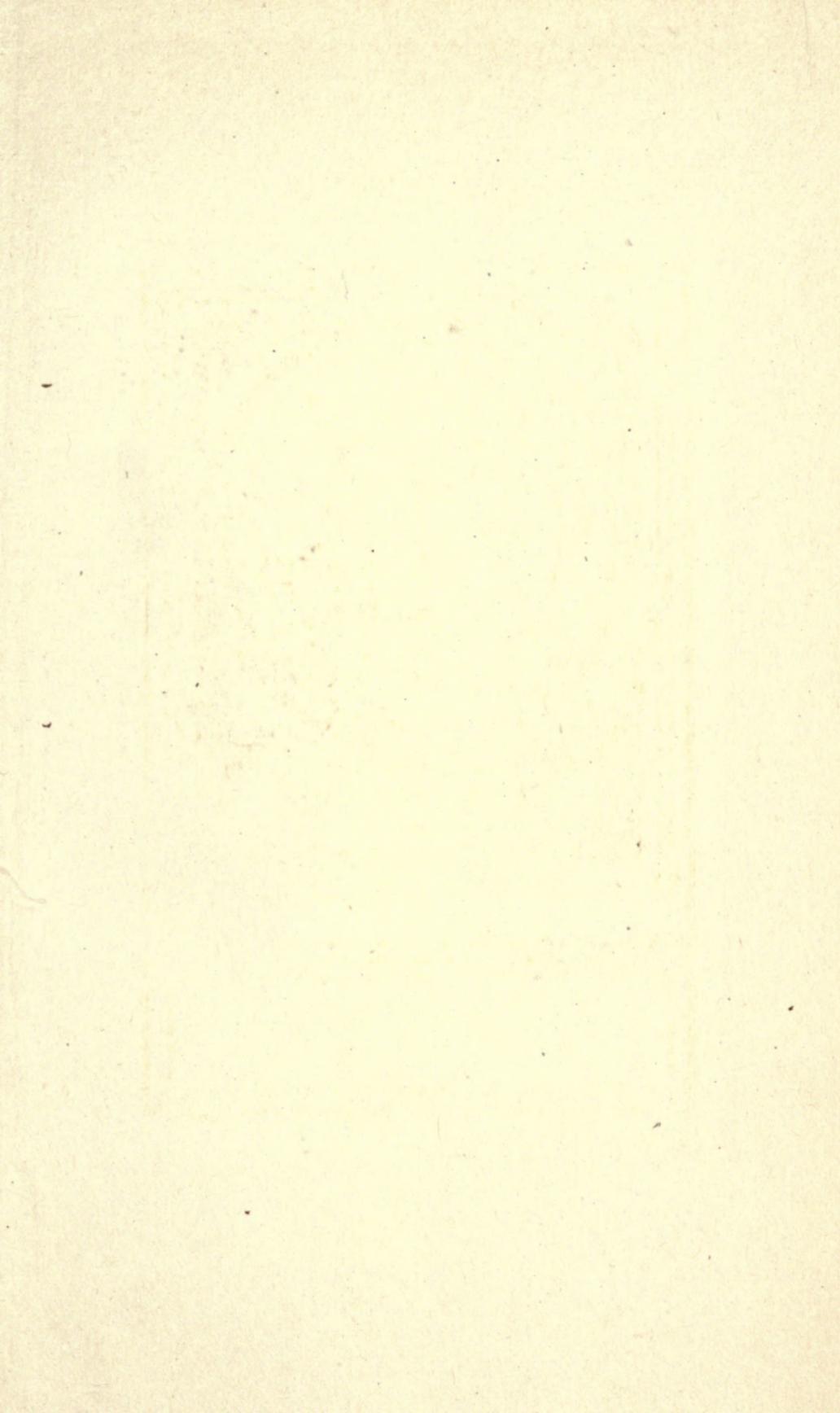


JEFFERY

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TEXT-BOOK OF LAND DRAINAGE

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TEXT-BOOK
OF
LAND DRAINAGE

BY

JOSEPH A. JEFFERY

LAND COMMISSIONER DULUTH SOUTH SHORE AND ATLANTIC
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MICHIGAN AGRICULTURAL COLLEGE



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1916

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Norwood Press

J. S. Cushing Co. — Berwick & Smith Co.
Norwood, Mass., U.S.A.

AUTHOR'S PREFACE

THE low yields of farm crops in this country are frequently used as a basis for speculation as to the future limit of food supply. The causes for these low yields are variously estimated. Bad management, over-cropping, loss of soil fertility, washing away of soils, "changing climatic conditions," and even "over-drainage" are among the more prominent of the causes named. "Bad management" is a very comprehensive term. "Loss of soil fertility" is a much used expression, but indifferently understood. Sometimes it is properly applied, but in many cases it probably does not apply except in so far as it may be synonymous with malnutrition of the crop.

The improper functioning of common soils, because of the extended presence, at some time during each year, of excessive amounts of water, is seldom mentioned; and yet one needs but to travel through the land with an observant eye in the cropping season to discover areas (even in the so-called "garden spots") where half stands exist, fourth stands, and actually no stands for a half field or whole field, indicating failure in germination or very soon thereafter. He discovers sickly full stands, half stands and less; also drowned areas, and places where no crops have been planted—"skipped areas"—in fields that in other parts have a thrifty appearance of crops.

It is difficult, indeed, to estimate the losses resulting from such conditions. There can be no doubt that if many of these fields could function as well over their whole areas as in their best parts, their average yields

would be very markedly increased. It is equally true that if all the lands on all the farms were properly drained and given the chance to do their best, total yields and total averages would be enormously augmented.

These losses and the means of correcting them are the theme of this text. In the preparation of the material for the volume, an attempt has been made to put into simple and concise terms the fundamentals of our knowledge concerning the relation of water to agriculture, and of the relation of drainage to soil water. The practical farmer has been in mind much more than the engineer. Material has been introduced at the risk of the charge of repetition, or even of the incorporation of extraneous material, and for these reasons:

1. That many persons who may use the work will not have had a sufficient knowledge of these matters to appreciate the importance of drainage in agricultural practice.

2. That many persons, including college men, who may have taken courses in the physics of soils, will not have sufficiently correlated the knowledge so acquired to appreciate the inter-relations between the physical conditions existing in soils, nor, consequently, the importance of drainage in agricultural practice.

3. The constituency is various. While designed specially as a text for students, it is hoped that the book will find a place with the working farmer.

Acknowledgments are due to various friends for information and suggestions in the preparation of the manuscript. Acknowledgments are especially due to Dr. George J. Bouyoucos and Charles H. Spurway, who were at one time associated with the author in College work.

JOSEPH A JEFFERY.

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TEXT-BOOK OF LAND DRAINAGE

LAND DRAINAGE

CHAPTER I

CHARACTERISTICS OF SOILS

NEXT to the soil itself, water is the most important factor in crop production. Without it, crops cannot be grown. Its abundance is desirable, but its control is more important than its abundance. Its control is important not only because of the immediate functions of the water, but because also of the degree to which its presence or absence may affect other factors essential in crop production. A brief study of these relations is essential to an understanding of the subject before us.

1. Chemical and physical composition of soils. — A soil of good chemical composition is one in which all of the food elements which crops obtain directly from the soil are found in abundance.

A soil of good physical composition is one in which organic matter (chiefly vegetable materials) and the various kinds of mineral matter — sands, silt, and clay — exist in desirable proportions.

A soil lacking in chemical and physical composition cannot normally produce a good crop. On the other hand, it does not follow that fit chemical and physical compo-

sition of a soil will insure a crop. A soil may be of good character in these respects and yet fail absolutely to produce a good return.

2. Physical condition of soil. — The physical condition of any soil bears a profound relation to its ability to produce a crop. It is undoubtedly safe to assert that soils more frequently fail to produce large or even satisfactory yields because of improper physical condition, than because of improper chemical or physical composition. The physical conditions of soil upon which plant growth most largely depends are: proper temperature; proper ventilation; proper structure, or tilth; proper moisture.

TEMPERATURE

There are three lines of activity within the soil having to do with the welfare of the crop: (1) food preparation, (2) germination, (3) root activity; to which may be added (4) recuperation.

3. Food requirements of plants. — The chief food elements required by plants are: carbon, oxygen, hydrogen, nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, chlorine, and iron. Each of these is always combined with one or more other elements before plants can use it for food. The carbon is combined with oxygen, forming carbon dioxide; the calcium is combined with carbon and oxygen, forming calcium carbonate¹; the nitrogen is combined first with hydrogen and oxygen, forming nitric acid (HNO_3), and then exchanging the hydrogen for some other element, such as calcium or potassium, to form calcium nitrate ($\text{Ca}(\text{NO}_3)_2$), or potassium nitrate (KNO_3).

¹ Probably changed to nitrates before reaching the plant.

TABLE I

PLANT-FOOD ELEMENT	SYMBOL	FORM IN WHICH WE ARE MOST LIKELY TO THINK OF IT	FORMULA
Carbon . . .	C	Carbon dioxide	CO ₂
Oxygen . . .	O	Water	H ₂ O
Hydrogen . . .	H		
Nitrogen . . .	N	Nitrates	Ca(NO ₃) ₂ - KNO ₃
Potassium . . .	K	Potash	K ₂ O
Phosphorus . . .	P	Phosphoric acid	P ₂ O ₅
Calcium . . .	Ca	Lime	CaO
Magnesium . . .	Mg	Magnesia	MgO
Sulfur . . .	S	Sulfuric acid	H ₂ SO ₄
Chlorine . . .	Cl	Common salt	NaCl
Iron	Fe	Iron oxide	Fe ₂ O ₃

The plant secures its carbon as carbon dioxide, which is a gas, from the air through its leaves.

All other foods the plant secures from the soil through its roots. (Fig. 1.)

4. Temperature and food preparation. — The wise farmer begins the preparation of a field some time, if possible, before he expects to plant the crop. He has learned that with a reasonable period given to such preparation, the crop responds more quickly after planting, grows better and yields better, than if the period of preparation is shortened. One of the reasons for this better behavior of the crop is that the period of preparation makes it possible, under normal conditions, to develop and store in the soil an abundant supply of available plant-food prior to the time of planting. Plants resemble animals in some of their food demands. They need a proper supply of food in the earlier days of their existence. Like animals, they are likely to show, during the remainder

of their lives, the effect of an abundance or a shortage of food in these earlier days.

5. **Chemical and physical activities.** — All the mineral plant-food elements are found in all normal soils, and are

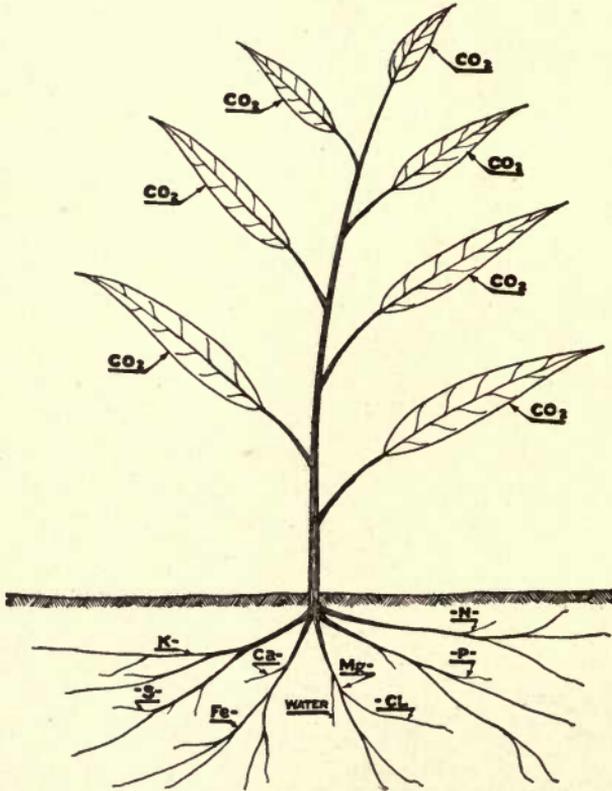


FIG. 1. — Drawing to show how the plant receives its several food elements. Each is always combined with one or more others.

taken by the plant from the soil through its roots. Each element exists as a chemical component of some one or more of the mineral¹ parts of the soil. Before they can

¹ "The few elements which exist free as constituents of rock, together with many definite compounds of elements which naturally take the solid form, are minerals." — BLACKWELDER AND BARROWS.

be used by the plants, these food elements must be separated from the mineral particles and be dissolved in the soil water. Whether these changes are chemical or physical, they take place more readily and more rapidly under high than under low soil temperatures.

6. Biological activities. — The plant secures its nitrogen supply from the soil also, and appropriates it by way of its roots. The greater part of this nitrogen supply must be in the form of nitric acid, usually after the acid has combined with some mineral element, such as calcium or potassium, thus forming what is called a nitrate. The greater part of the nitrogen supply in the soil is in some form other than nitric acid or nitrate. It is chiefly locked up in the organic matter; or it is found as free nitrogen in the air in the soil.¹ There is some ammonia and some nitrous acid in the soil, and these are nitrogen compounds.

7. Nitrogen preparation. — Before the nitrogen of the organic matter in the soil can be used for food by growing crops, it must enter into new combinations with other elements. The greater part of the nitrogen, by a series of changes, is finally combined with hydrogen and oxygen to form nitric acid (HNO_3), which in turn combines with some base to form a salt. It is in this form chiefly that nitrogen is used for food by plants.²

¹ Air is composed of a mixture of gases, of which mixture oxygen constitutes 23.22 %, nitrogen 75.55 %, and carbon dioxide .045%-.06% by weight. — HILGARD, *Soils*, p. 16.

² Recent investigation indicates that plants use, to some extent at least, other forms of nitrogen than nitric and ammonia nitrogen. See article of H. B. Hutchinson and N. H. Miller of the Rothamsted Experiment Station, which appears in the *Journal of Agricultural Science*, Vol. 3, part 2, 1909. See also Bulletin 87, Bureau of Soils, U. S. Dept. Agr.

8. Temperature and nitrification. — All the changes by which organic nitrogen is put into form for use by plants are accomplished chiefly by bacteria. It has been found, according to Schloessing and Müntz and other authorities, that these changes proceed very slowly when the temperature of the soil is not higher than 54° F. They proceed most rapidly when the soil temperature is near 98° F. Recent research seems to indicate an optimum temperature as low as 85° F.

9. Nitrogen fixation. — On the roots of all leguminous plants, under normal conditions, are found colonies of another class of life forms, usually spoken of as bacteria, which possess the power to appropriate the free nitrogen of the soil air and combine it with hydrogen and oxygen to produce a form of nitrogen which the host plant can and does use for food. These forms are called nitrogen-fixers, and the process is sometimes called nitrogen fixation. They work most rapidly when the soil temperature ranges from 90° to 100°. These bacteria are in enlargements of tissue known as nodules.

There are probably other forms of bacteria and some forms of molds in soils that have this power of nitrogen fixation, and their rate of work is greatly affected by temperature conditions.

10. Temperature and germination. — Most crops are grown from seed. There is a temperature below which seeds will not germinate. There is also, for each kind of seed, a temperature at which it will germinate most quickly. In Table II are shown some of the findings of Sachs and Van Tiegham regarding the lowest, highest, and best temperatures for the germination of the seeds indicated. See also Table III.

TABLE II

RANGE OF TEMPERATURES AT WHICH SEEDS HAVE BEEN FOUND TO GERMINATE

KIND OF SEED	LOWEST TEMPERATURE AT WHICH THE SEED WAS FOUND TO GERMINATE	TEMPERATURE AT WHICH THE SEED GERMINATED MOST QUICKLY	TEMPERATURE ABOVE WHICH SEEDS WOULD NOT GERMINATE
Wheat . . .	41° F.	81° F.	104° F.
Barley . . .	41°	83°	104°
Peas . . .	44½°	84°	102°
Maize . . .	48°	93°	115°
Squash . . .	54°		115°
Red clover . .	42° Van Tiegham	70°	

TABLE III

DAYS REQUIRED FOR RADICLE TO APPEAR WHEN SEEDS ARE PLANTED AND KEPT AT THE TEMPERATURES INDICATED¹

SEEDS	DAYS AT TEMPERATURES INDICATED			
	40° F.	51° F.	60° F.	65° F.
Barley and wheat . . .	6	3	2	1¾
Beans	7	6½	4¾	4¼
Clover, red	7½	3	1¾	1
Flax	8	4½	2	2
Maize		11¼	3¼	3
Oats	7	3¾	2¾	2
Peas	5	3	1¾	1¾
Pumpkin			10¾	4
Rye	4	2½	1	1
Sugar beets	22	9	3¾	3¾
Timothy		6½	3¼	3

¹ A part of Haberlandt's findings as quoted in Warington's Physical Properties of Soil, p. 140.

The days indicated under the several temperatures, and after the seeds, undoubtedly indicate the time required for the radicle to burst through the coat of the seed, not the time required for the radicle to appear above ground. (See Fig. 4.)

More recent investigators assert that some of these seeds do germinate occasionally at temperatures lower than those indicated in the above tables. The late C. F. Wheeler found that chess seed would germinate when lying on a cake of ice in a refrigerator, and send roots $\frac{3}{4}$ inch into the ice. Wheat and other grains are not infrequently sown, in the Northwest, when the soils are thawed but six or even four inches deep in the spring; they germinate in a short time, long before the frost has entirely disappeared below the seed-bed. In such cases, the seed-bed possesses a temperature much above that of the frozen ground below.

11. Desirable temperature condition. — The best and most desirable temperature is one ranging from 70° to 90° F. The question that should be uppermost in the farmer's mind is not "at how low temperature will seed germinate," but rather "what means may I employ to bring the temperature of the seed-bed to most nearly approximate the ideal?" In Fig. 2 are shown the effects of temperature on germination. The three jars were prepared alike, and each had ten kernels of corn, from the same ear, planted in it. The jars were then placed one in a temperature of 55° F., one in a temperature of 70° F., and one in a temperature of 85° F. The photograph was taken on the eighth day from planting.

12. Later effects. — If, on the eighth day, the jars shown in Fig. 2 were placed together, and allowed to remain in a temperature of 75° to 85°, most, probably all, of the

seeds in the jar marked 55° would germinate. If the seed used in all the jars were of inferior quality, undoubtedly a smaller percentage of them would germinate in jar marked 55° , than germinated in either of the other jars. It is more than probable that in their later growth, these corn plants would never overtake the plants in jar marked

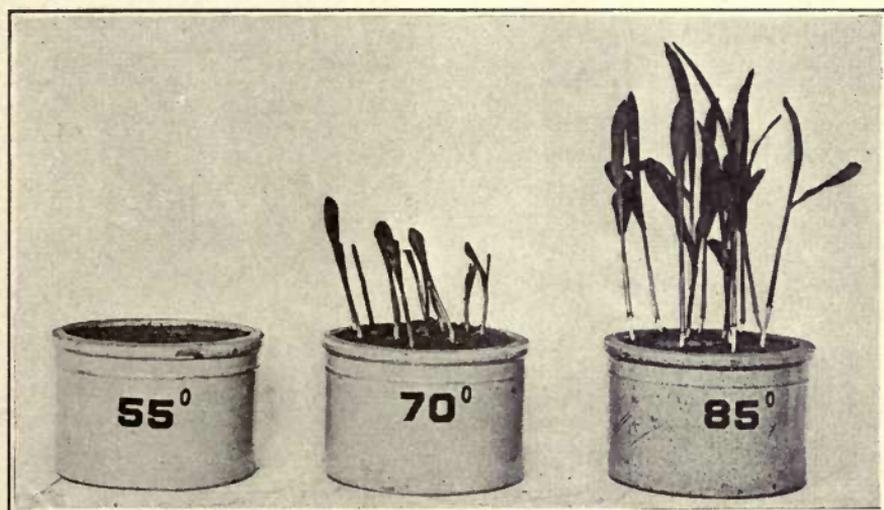


FIG. 2. — Effects of temperature on germination. The jars have indicated upon their sides the temperatures — 55° , 70° , and 85° respectively — at which the jars were kept after the corn was planted in them. The picture was taken 8 days after planting.

85° , and would never show the vigor and healthfulness of the plants in that jar. It is also probable that the plants resulting from the germinations occurring at 70° would never fully overtake the plants resulting from the germinations at 85° , or show the same vigor.

13. A rare case. — Some years ago, in southern Wisconsin, a field unusually well prepared, in a season of very favorable temperature conditions, was planted to corn. In three days the young corn plants were above ground sufficiently to be easily “rowed” diagonally, as

well as lengthwise and crosswise. A duplication of this incident has not been discovered in forty years of observation. The later behavior of the crop was entirely in accord with these early days of its history — a seemingly uninterrupted growth, early crop maturity, and an abundant yield. This example illustrates the importance of a good start, due to many favorable conditions.

14. Temperature and root action. — The plant receives all of its food, excepting carbon, through its roots. This food can be taken only after it is dissolved in large quantities of water. The plants on an acre of oats, yielding 50 bushels of grain, would take through their roots during their growth at least 700 tons — 1,400,000 pounds of water.¹ This water is required to dissolve the plant-food, to assist it to reach its place in the plant, and generally to assist in promoting the well-being of the plant. The part the roots play in taking in this great quantity of water is involuntary, excepting as they place themselves in position to receive it. The process by which this soil water enters the roots is called osmosis; that by which the foods in solution move inward to be used by the plant, diffusion. Both water and food enter the roots from the soil chiefly, if not entirely, by way of the root-hairs. It is important, therefore, that the plants develop extensive and vigorous root systems. In all of this, temperature becomes an important factor.

15. Root pressure. — When a soil is over-cold, the rate at which water enters the roots growing upon it may be so slow that the plants assume a wilted appearance.

¹ This is in accord with the best service of water reported by King, but is much below that obtained under arid conditions and under very close control by Briggs and Shantz, and reported in No. 1, Vol. III, Journal of Agricultural Research.

Every one acquainted with crops will recall how rigid — even to tender crispness — are the leaves of a corn plant in the early morning, when growing in warm moist soil. The leaves would not be so crisp, and might even appear wilted, if the soil were too cold.

16. Root development. — As the part of the plant above ground develops from the seedling to the mature plant, its demands for food and anchorage increase; since the part of the plant underground must furnish both, there must be adequate development underground also. Few realize how great this development is. King, in what seems to be a conservative estimate,¹ has shown that the roots of a single healthy corn plant, placed end to end, would amount in length to not less than one-fourth mile, and probably would often much exceed this. It is only when the soil temperature is correct that this great development can be most satisfactorily made.

17. Best temperature for root action. — The temperatures best suited to food preparation and for germination are also good for root activity as regards both growth and feeding. Hall gives 83.6° F. as the optimum soil temperature for growth of barley and wheat, and 92.6° F. as the optimum for maize and kidney beans. He gives 93° F. as the temperature at which maize roots made their maximum growth — 55 millimeters in 24 hours.² These temperatures, with a single exception, are higher than the highest averages of observed temperatures shown in Table IV. The exception is for 1 inch deep in Nebraska soil.

18. Temperature and the rest-period. — The period elapsing between the harvesting of one crop and the plant-

¹ King, *The Soil*, p. 210.

² Hall, *The Soil*, p. 114.

ing of the next is no doubt often thought of as one of rest as synonymous with idleness. It is not often considered as a period of rest in the sense of recuperation, as it should be. After producing certain crops, and especially under abnormal weather conditions, the soil is found to be in a very unsatisfactory physical condition, and one in which the evils are cumulative, or may easily become so if proper precautions are not taken. Who has not seen the wheat field, the oat field, and even the bean field, so baked and scorched as to make it seemingly impossible of preparation for an immediate crop? In this condition of intensely high temperature and dryness, not only are certain important processes suspended, but undoubtedly much of the desirable microscopic flora is destroyed.

19. Actual temperatures. — In the humid part of the United States, soils under normal weather conditions are seldom, if ever, too warm for the ordinary crops. The opposite is more likely to be true, so that when the tiller has exercised his highest art in soil management, the temperature still ranges too low for the best results in cropping. In Table IV data have been assembled to show average soil temperatures for the growing months as gathered at rather widely distributed points and under different conditions. Note the average soil temperature for 6 inches deep in parts 1, 2, 3, and 6 of the table. Observe that in no case does the average reach the optimum for seed germination. This does not occur even at 1 inch deep in Nebraska, nor at 3 inches deep in Geneva.

It should be borne in mind, however, that these temperatures are expressed as monthly averages. On some days the maximum temperature would much exceed the average of the month, and even at 6 inches deep might approach optimum.

The average air temperatures for Nebraska, Tübingen (Germany), and Geneva (Switzerland) are lower than surface and near surface temperatures. The Michigan air temperatures were recorded by an instrument not shaded from the direct rays of the sun.

TABLE IV

CONDITIONS	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.
1. Temperature averages for 12 years at the Nebraska station						
Air temperatures . . .	52.1	61.9	71.0	76.0	74.5	67.6
Soil at 1 inch . . .	57.5	68.7	78.1	85.1	82.9	73.8
Soil at 6 inches . . .	53.3	65.1	75.7	81.6	80.1	72.0
Soil at 12 inches . . .	49.3	60.7	69.9	75.7	75.7	69.2
2. Temperature averages for 5 years, Pennsylvania station (Frear)						
Soil at 6 inches . . .	43.08	54.72	66.34	69.75	68.49	61.70
Soil at 12 inches . . .	42.69	53.83	65.03	68.89	68.66	62.73
3. Temperature averages for 4 years, Munich, Germany (Ebermeyer)						
Soil at 5.9 inches . . .	44.65	56.79	61.11	67.26	64.09	58.21
Soil at 11.8 inches . . .	44.31	57.51	60.06	66.16	63.61	57.88
4. Midday temperature averages on fine days for two seasons, Tübingen, Germany (Schübler)						
Surface of soil . . .	121.6	131.2	139.8	146.3	130.1	119.8
Air	61.7	67.3	75.2	81.3	68.9	68.0
Excess of surface over air	59.9	63.9	64.6	65.0	61.2	51.8

5. Geneva Society — Variable weather averages for one season,
Geneva (Schübler)

Surface	78.9	80.1	89.1	93.4	96.0	82.8
Soil at 3 inches . . .	60.7	64.4	73.6	73.3	76.9	70.2
Air in shade	50.1	55.9	60.9	63.2	65.8	62.4
Surface over air . . .	28.8	24.2	28.2	30.2	30.2	20.4
3 inches deep over air	10.6	8.5	12.7	10.1	11.1	7.8

6. Temperature averages for one season, Mich. Exp. Station
(Bouyoucos)

Loam soil 6 inches . .	39.16	55.07	66.28	72.40	67.82	65.76
Loam soil 12 inches . .	37.47	53.02	63.88	70.55	67.00	65.82
Clay soil 6 inches . . .	40.20	56.00	66.51	72.20	68.01	65.56
Clay soil 12 inches . .	38.44	53.43	63.89	70.15	66.92	65.56
Peat soil 6 inches . . .	34.04	55.61	67.15	73.30	68.60	66.37
Peat soil 12 inches . .	35.48	52.00	64.24	68.56	67.22	66.44
Air in sunshine	50.22	62.00	70.78	75.77	72.34	68.90

VENTILATION

Soil ventilation does not differ essentially from house ventilation. It involves the displacement of bad or vitiated air by pure air. There are several reasons why a soil should be ventilated.

20. Ventilation and food preparation. — The breaking down of the minerals of the soil and the consequent liberation of contained plant-foods are favored by the presence of the oxygen of the air. The processes referred to in paragraphs 7 and 9 by which the nitrogen is changed, step by step, from non-usable to usable forms, can take place normally only when an abundant supply of oxygen

is present. The germs that bring about these changes cannot work without oxygen. The nitrogen-fixation bacteria must have free nitrogen to work with and oxygen to assist them.

21. Prevention of food destruction. — Probably most soils contain certain kinds of bacteria that, while they require oxygen for their well-being, are not entirely de-

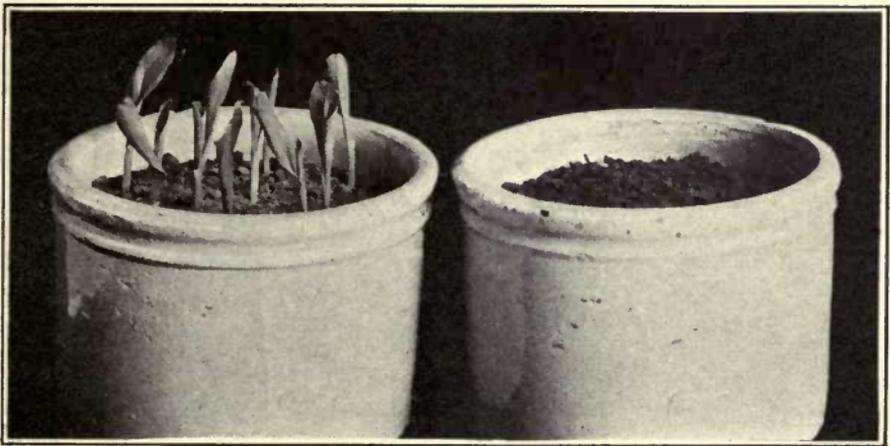


FIG. 3. — The effect of ventilation on germination. The air was excluded from the soil in right jar by flooding to a depth of $\frac{1}{2}$ an inch with water. Picture taken 7 days from planting. One hundred per cent of the kernels in left jar germinated.

pendent upon air for their oxygen supply. In the absence of air oxygen, they have the power to destroy certain chemical compounds for the oxygen these compounds contain. The nitrates are among the compounds they can destroy. Nitrates, it will be remembered, are the forms of nitrogen that are most used by growing crops.

When the air is excluded from a soil containing nitrates, the germs attack the nitrates and remove the oxygen from them, and by this act render the nitrogen of the nitrates useless for the crops. The rate at which this

destruction takes place may be very rapid. The germs have been known to destroy, in two weeks, enough nitrate to produce a crop of wheat.¹ The process is called denitrification, and the germs, denitrifiers.

22. Ventilation and germination. — The seeds of plants cannot germinate in the absence of oxygen. Corn kept

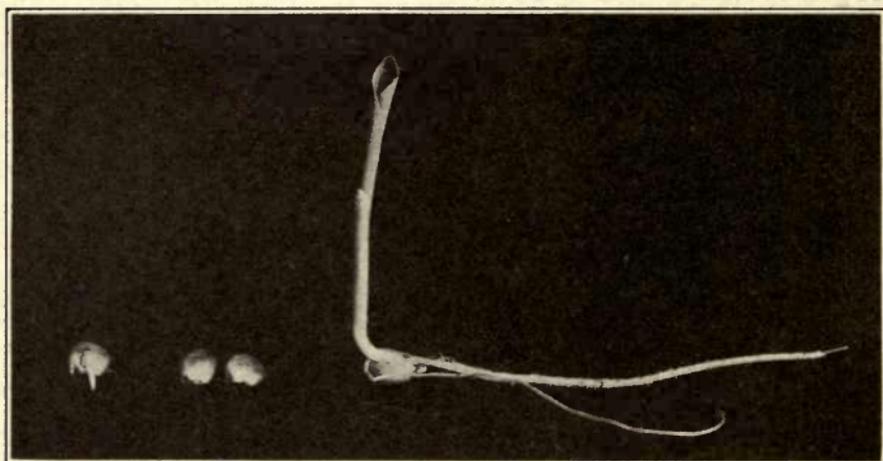


FIG. 4. — The effects of ventilation on germination. The plant at the right is taken from left jar, Fig. 3. The two kernels in the center were taken from right jar, Fig. 3. They show absolutely no indications of germination. The kernel at the left was taken from a germinator after 3 days. It shows the radicle making healthy growth.

in a completely water-logged soil will never germinate. If, before the vitality of the kernels is destroyed, the water is removed from the soil and air permitted to come to the kernels, they will germinate, but the vigor of the resulting plant is likely to be impaired, perhaps seriously if the germination has been much delayed. The partial exclusion of air from seeds must retard germination, and often

¹ The writer has found that under water-logged conditions, scarcely a trace of nitrates remained after 72 hours, where originally large quantities existed.

seems to reduce the vitality of the resulting plants. (See Figs. 3, 4, 5, and 6.)

23. Ventilation and root action. — In the absence of oxygen, the roots of common plants not only cannot perform their functions, but they quickly die. If all the roots die, the remainder of the plant also dies, and if any

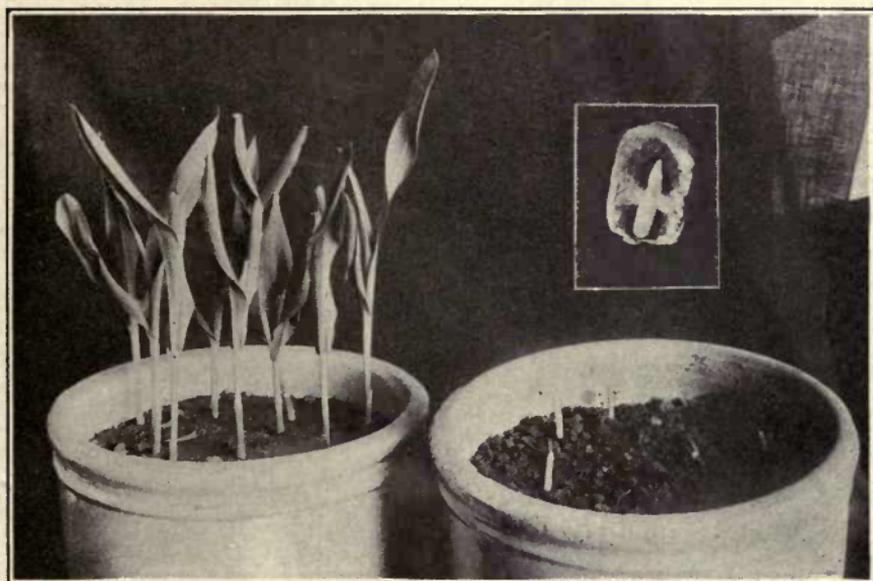


FIG. 5. — Effects of ventilation on germination. Same as Fig. 3, 11 days from planting; 4 days after the excess of water had been removed from right jar. Fifty per cent only of the kernels have germinated. In the upper right quarter of the cut is shown a kernel of corn with the embryo exposed.

considerable part of the root system is destroyed, the remainder of the plant must suffer, even if it is not killed. Most crops drown very quickly, for the same reason that animals do. Mention was made in paragraph 16 of the great development made by the root system of the corn plant. The root systems of all our crops are extensive. In the absence of oxygen, the roots die. When the supply

of oxygen is restricted, the growth of roots is retarded and the crops suffer.

24. Removal of objectionable products. — All growth results in the production of carbon dioxide. Animals throw this gas from their lungs into the air. The roots

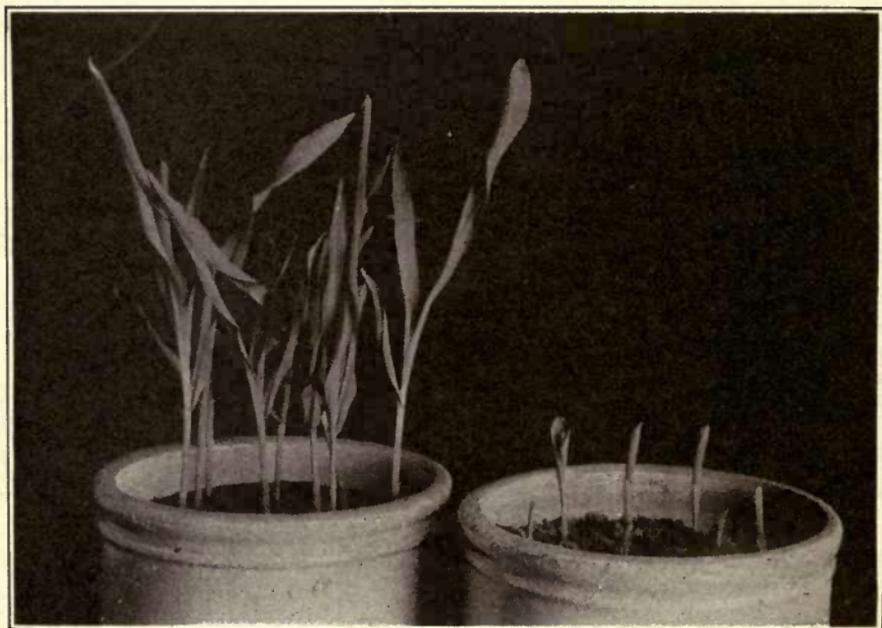


FIG. 6. — Effects of ventilation on germination. — Same as Fig. 3, 14 days from planting; 7 days after water was removed from right jar. Seventy per cent only of the kernels have germinated.

of plants and the lower plant forms growing in the soil produce carbon dioxide (CO_2) and liberate it in the soil. The presence of carbon dioxide (CO_2) interferes with the life in the soil, as does its presence with animal life in a room. When, therefore, there is an unbalanced condition of air in the soil, — too little oxygen, too much carbon dioxide, — the balance must be reestablished before plant life can thrive.

SOIL STRUCTURE

Soil texture has reference to the sizes of the soil particles and the proportions in which the various sizes of particles exist in the soil. Texture is not greatly subject to modification or control, and is rather stable.

Soil structure has reference to the manner of arrangement of the soil particles. The particles in a soil mass may lie in very close contact with each other. Under some conditions the soil particles may be cemented together by certain salts existing in the soil. Except possibly in coarse soils, the former condition is very undesirable. The latter condition is undesirable in any soil. It is best illustrated in puddled or "baked" soil, and in the hard-pans.

25. Ideal condition of structure. — When a soil proper crumbles readily into a soft mass under the pressure of the hands, and readily becomes loose — mellow — from the action of tilling and stirring tools, it may be said to approximate the ideal condition of structure, or tilth.

While the subsoil will seldom break down in the same way, it should crumble also, but usually into somewhat larger masses, cuboid in shape. This would indicate that the whole mass of the subsoil, as it lies in position, is already separated into these small cubes (cuboids) by a very great number of cleavage planes. More will be said of these planes in another paragraph, (47).

26. Over-mellowness. — Some soils, and especially those in arid or semi-arid climates, possess a structure such that the plow renders them over-mellow for immediate planting. Such soils must be plowed some time before planting the crops upon them, — frequently in the fall when the planting is to be done the following spring.

On such soils, except when a sod is to be turned down, the disk harrow is to be preferred to the plow, when the planting must be done at once. The same discussion may apply to very sandy soils also.

27. Structure and germination. — On clay soils or heavy loams, a severe rain, just after the seed has been planted, will frequently so pack the soil that many of the seeds will fail to germinate, or the germination may be greatly delayed. Of the seeds that germinate, many will fail to thrust the parts out of the ground, and many others will be greatly delayed.

Seeds planted in over-loose or in over-lumpy soil may fail to germinate, or may be so delayed that at harvest time some plants will have ripened their seed, while others will have brought them only to the milk stage, or even to the flowering stage. (See Fig. 20.) Obviously soil structure plays an important part in germination.

28. Structure and root development. — Mention has already been made of the extent of the development of the root systems of our domestic plants, and of the need of the plant for such root development to secure both food and moisture. The tender tips of the developing rootlets can penetrate a hard or compact soil but slowly, and, therefore, for but relatively short distances. The root system developed under such conditions will be marked by short roots and fewer of them. Therefore the crop suffers.

29. Root development restricted by fissuring. — In a soil (or subsoil) checked by large fissures or cracks, a root may advance to the fissure and grow out into it, but will find difficulty in making an entrance into the opposite wall, especially if the soil of the opposite wall is hard as is almost sure to be the case where large cleavages

occur. The roots are more likely to advance along the fissure, and most of their usefulness to the plant is thus lost.

30. Injury to roots by fissuring. — When fissuring or cracking occurs in soils or subsoils already filled with active roots, all those roots lying across the plane of the fissure are almost sure to be broken, and their service beyond the breaks, and that of all their branches is lost to the plants to which they belong. Crops, therefore, may suffer greatly from soil fissuring.

WATER

Water is the great servant of nature. It is also the great servant of agriculture, and its usefulness is proportional to the degree of its successful control. Its functions are many.

31. Moisture and food preparation. — In the preparation of food, water plays a most important part. Few, if any, chemical reactions can take place in the absence of moisture. Moisture, in contact with the surface of the soil particles, assists in the actions resulting in the liberation of the plant-food which the soil particles may hold.

Those germs, usually designated as nitrifiers, whose important function it is to transform the unusable nitrogen of the organic matter of the soil into usable nitrogen, cannot perform their work without moisture; nor can they grow and multiply without moisture. The forms engaged in nitrogen fixation cannot work in the absence of moisture. These are the forms which we know best, as they are found established on the roots of the clovers, beans, alfalfa, and other legumes.

A soil constantly deficient in moisture is almost sure to be deficient in all these useful nitrogen preparers, as well as one which is over supplied with water.

32. Moisture and germination. — Water plays a very important and interesting part in germination. Seeds would lie indefinitely in a dry soil without germinating; but where there is proper moisture, and correct conditions of temperature and ventilation, the water makes its way through the seed-coat and causes the seed to swell till it bursts its coat. At the same time the presence of the water in the seed promotes certain changes by which the food stored in the seed is made ready for the use of the young plant (more correctly called a plantlet or embryo). (See Fig. 5.) It uses the food, begins to grow out through the ruptured coat, and is soon established in the soil. By the time, or even before, it has used up the supply of food stored for it in the seed, it is ready to use the food supply provided in the soil.

33. Water the solvent and carrier. — Before the young plant can use the foods stored for it in the seed or in the soil, the food must first be prepared and then dissolved in the soil water. The water thus becomes the carrier of the foods. The food-laden water may move considerable distances through the soil to the roots. On the other hand, when the soil is in proper physical condition, the roots develop remarkably, as was indicated in paragraph 16. They reach out considerable distances, and at the same time their branches become very numerous,¹ so that there is not a cubic inch of soil for some feet from the plant that is not penetrated or traversed by at least one root — more usually by several.

¹ There are few of our common crops that fail to produce roots as much as three feet in length, and some exceed ten feet.

Only a brief outline can be given, in this discussion, of the way in which this feeding process takes place. This general statement is sufficient to indicate the general part that water plays in the work.

34. Service of water within the plant. — Within the plant, the water continues to be the carrier of the food. It delivers its load to the leaves. There the food is elaborated and much of the water is dismissed into the air by way of openings in the leaf walls. Some of the water is still retained, a part of it to be used by the plant as food, and the remainder to continue its service as carrier; but its burden now is elaborated food, and its function is to distribute this food to the parts requiring it for growth or storage. Some of it is carried to the stems, some to the leaves, some to the maturing seeds, and some even to the extreme ends of the roots.

35. Quantities of water required by crops. — Most of the plant-foods are only slightly soluble in water; that is, a large quantity of water is required to dissolve a small quantity of food. Storer states that, in ordinary soils, a thousand pounds of water can dissolve from one half to one and one half pounds of mixed organic and mineral matters.¹ For this and other reasons, large quantities of water are required to produce a good crop yield. When the water supply is short, the crop yields are necessarily lowered. Table V is a modification from King and has been prepared chiefly to show the least possible amount of water that may be expected to produce the yields indicated in the first column of the table. The required amounts are expressed both in tons and in inches of rainfall. These amounts include the losses by evaporation from the surface of the ground in the growing season,

¹ Storer, *Agriculture*, Vol. I, p. 285.

which must be kept at a minimum. Few farmers, however, obtain this service from water.

TABLE V

CROP AND YIELD TO THE ACRE	ACRE-INCHES	TONS OF WATER	LARGEST POSSIBLE YIELD FROM 8 INCHES RAINFALL
20 bu. wheat	6.0	680.0	26.66
35 bu. wheat	10.5	1190.0	
40 bu. oats	6.27	710.6	51.02
65 bu. oats	10.19	1154.0	
30 bu. barley	6.42	727.4	37.38
45 bu. barley	9.63	1091.40	
40 bu. corn	6.72	761.5	47.62
65 bu. corn	10.92	1237.00	
100 bu. potatoes	2.07	234.62	386.47
300 bu. potatoes	6.2	702.60	

In the fourth column of the table are shown the yields of the several crops that should be obtained from eight inches of rainfall under the same conditions of efficiency.

36. Conditions of water.—Water may exist in the soil in any one of three conditions; as gravitational, as capillary, and as hygroscopic water.

37. Gravitational water.—That water in the soil which, if opportunity be given it, will flow downward or away through the soil because of its own weight, is gravitational water. Its tendency is to flow directly downward. Obstructions and restrictions of various kinds will turn it out of its course and cause it to flow in other directions—even upward, as is seen in a boiling spring (the stream of water rising out of the ground—not from heat). Water which in the soil would be grav-

itational water is surface water before it enters the soil. Surface water is that which stands upon or moves off over the surface of the ground. It must very often be taken into account in planning a system of drainage.

38. Capillary water. — The water that remains clinging to the walls of the soil particles with sufficient force to withstand the pull of its own weight is capillary water. It is often defined as the water that remains clinging to the walls of the soil particles after all gravitational water has moved away. It covers the walls in very thin layers. Just as the outer molecules of the water of a dew-drop hold the mass in a spherical shape, so the outer molecules of the capillary water covering the soil grains hold the water about the grains.

39. Hygroscopic water. — The water that is found in soil after it becomes air-dry is hygroscopic water. The amount of hygroscopic water in a given weight of soil usually depends upon three things, viz. the fineness of the soil particles, the temperature of the soil, and the humidity of the air in contact with the soil particles. The amount of organic matter in the soil becomes a fourth factor if it is not included in the first named. The humidity of the air may be roughly defined as the readiness with which it gives up its moisture. Some days the pitcher and the pump-spout "sweat"; some days they do not, depending upon the humidity of the air and the temperature of pitcher and spout.

The dust that rises from the road on a hot, sunshiny July day at noon, dry as it may appear, carries a measurable amount of hygroscopic moisture.

Opinions are not agreed as to the value of hygroscopic water in agriculture. It is probable that its presence results only in good.

40. Movements of soil water. — Mention has been made of three conditions in which water may exist in the soil. There are three movements of soil water — one each for these three conditions. Movements of gravitational water are known as gravitational movements; those of capillary water, as capillary movements; while movements of hygroscopic water are known as thermal movements. These movements are very distinct as regards their causes, characteristics, and agricultural importance. For the present, gravitational movements have been sufficiently discussed in paragraph (37).

41. Capillary movements. — Agriculturally, capillary water is preëminent. Its control, which is very desirable, is accomplished largely through the control of its movements, and this control depends largely upon a knowledge of their causes and character and the factors modifying them. Movements of capillary soil water are due chiefly to surface tension, and entirely so after the soil particles are invested by capillary water.

42. Surface tension. — When the rubber membrane of a toy balloon is inflated with gas, it assumes a spherical form, due to the pull of the membrane in its effort to contract. This lessens the volume of the gas, and because the pull is uniform, the balloon assumes a spherical form. (If some part of the rubber membrane were weaker or stronger than the rest, the form of the balloon would not be exactly spherical.) If a part of the inclosed gas were permitted to escape, the volume of the balloon would be reduced, but its form would not be changed.

The dew-drop, suspended from the blade of grass, does not go to pieces for the reason that the molecules of water covering the surface of the mass act in much the same way as the rubber membrane of the toy balloon.

If the dew-drop could be caused to stand in space, and freed from the pull of gravity, it would assume a perfectly spherical form. If any part of the water of the dew-drop could be removed, its size would be reduced, but its form would at once become spherical again, because of the pull

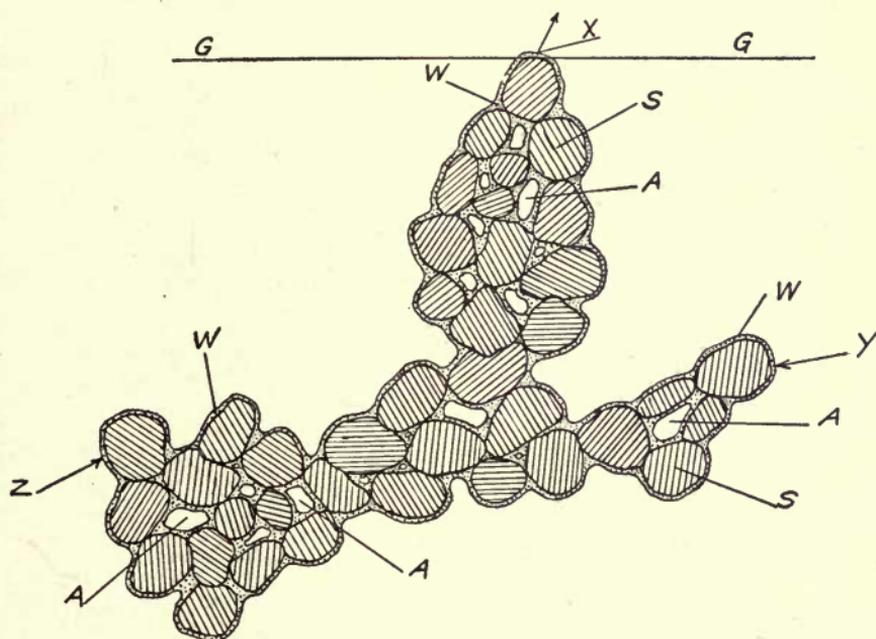


FIG. 7. — A mass of soil particles surrounded by capillary film, shown in section. *GG* represents the ground line; *S*, soil particles in section; *W*, water film; *A*, the air spaces surrounded by capillary films which in turn also surround the soil particles.

of the surface molecules. As a matter of fact, the dew-drop is not spherical as it hangs to the blade of grass. It is symmetrical, and its free surfaces are curved; the removal or the addition of water does not change these facts. Its new form will be symmetrical and its free surfaces curved, all due to the pull of the surface molecules.

When soil particles, or masses of soil particles, are invested with capillary water, the surfaces of the water

are always symmetrical, and are always exercising a compressing stress as they do in the dew-drop.

43. Direction of capillary movement. — If, therefore, capillary water is removed at some point in or on a soil mass, this compressing stress causes the remaining water to readjust itself so that the proportions of the thickness of water layer and the symmetry of the surfaces are the same as before the water was disturbed. (See Fig. 7.) In this readjustment of capillary water, the movement is along the surfaces of the soil particles and is always toward the point where the water has been removed, regardless of direction. If water is added at any point, a readjustment will take place and the movement will be away from that point, and out through the mass.

44. Hygroscopic movements. — These movements of water are called thermal movements, because heat is the chief factor involved in them. They take place from the surface of the soil particles into the surrounding air, or from the surrounding air to the surface of the soil particle.

CHAPTER II

PHYSICAL INTER-RELATIONS IN SOILS

A VERY intimate relation exists between each of the four fundamental physical soil conditions and all the others, and between gravitational water and all four conditions. So important are these relations that they should be very thoroughly understood. A brief description of them follows in the order of sequence as they appear to the writer.

INFLUENCE OF CAPILLARY WATER ON OTHER PHYSICAL CONDITIONS

45. Capillary water and soil structure. — The physical structure of a cultivated soil depends on four things, — the method of cropping, the organic matter present, the use of tools on the soil, and the moisture content throughout the year. This discussion permits the consideration of but one of these four categories, and but one phase of this — the function of capillary water.

46. Capillary water and plowing. — One of the uses of the plow is to mellow the soil. If a clay or a loam soil is plowed when over-wet, the earth is puddled or packed by the pressure of the mold-board upon it. The effect is much the same as if an over-wet piece of the same soil were squeezed in one's hand, or were rolled between the two hands. In either case, the soil so puddled is com-

pacted and dries more quickly than the unpuddled soil. In the field this puddling interferes (1) with the further

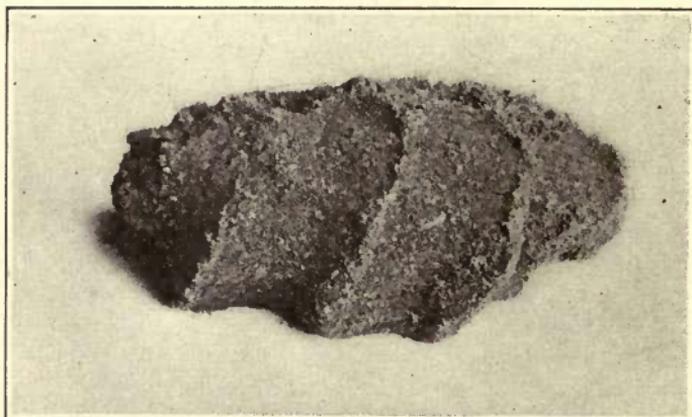


FIG. 8. — A mass of sandy loam formed under pressure of the hand and held in shape by capillary moisture. The capillary condition is ideal, as is proved in Fig. 9.

proper preparation of the seed-bed, (2) with proper planting of seed, (3) with germination, and (4) with root

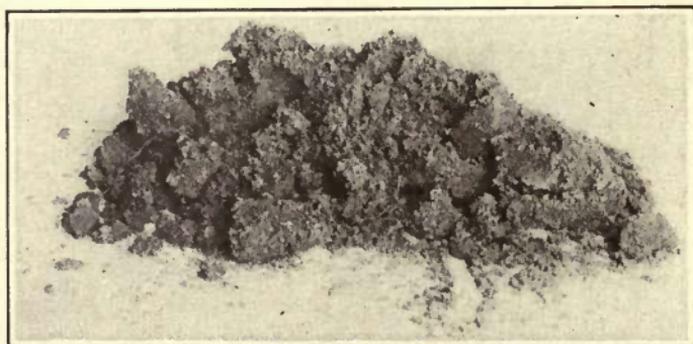


FIG. 9. — Same soil as shown in Fig. 8, but after a slight pressure of the fingers was applied. The soil has crumbled to a mellow mass.

development. The bad effects of a single plowing in over-wet soil may sometimes be apparent for several years following.

When a clay or loam soil is permitted to become over-dry, the plow turns it over in lumps, and no amount of work can properly fit it for an immediate crop. (See Fig. 20.)

47. **Correct moisture condition for plowing.** — Somewhere between the over-wet and the over-dry condition is the ideal moisture point. In clay soils and loams this is a capillary moisture condition, and is not the same for

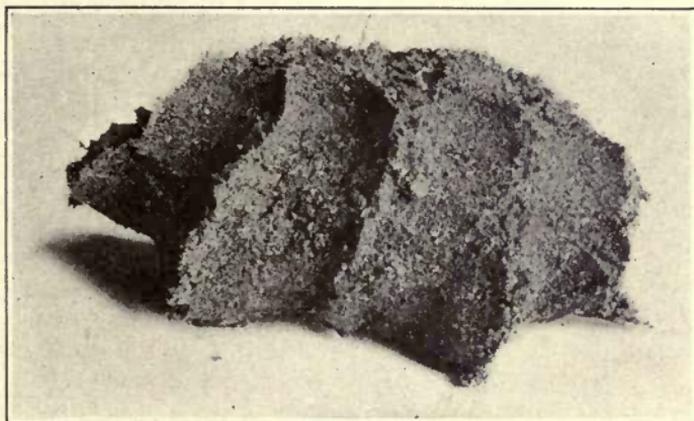


FIG. 10. — A mass of the same soil as is shown in Fig. 8, but with an over amount of capillary moisture, as is proved in Fig. 11.

every soil. Every experienced farmer recognizes this proper state of moisture and takes advantage of it, even resorting to artificial means to prolong its period until he can complete his plowing. When plowed in this condition, with the exception of the heavy clays, the normal soil falls away from the mold-board in a rather uniformly mellow mass. (See Fig. 19.) When in this state, a mass of the soil firmly crushed in the hand will retain its position when the pressure is removed, but when a rolling pressure is applied to it with the fingers, it readily crumbles. (See Figs. 8, 9, 10, and 11.)

48. Effect of correct plowing on the later preparation of the seed-bed. — When the soil is plowed under proper

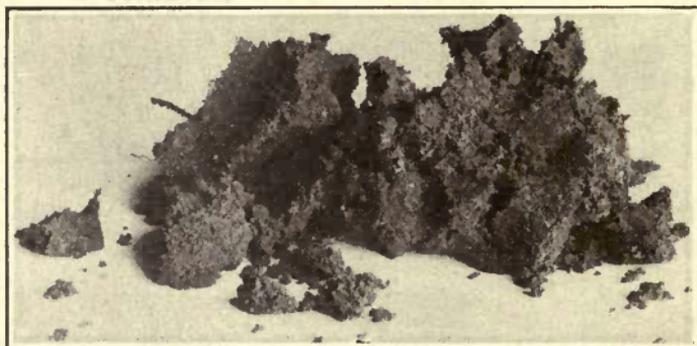


FIG. 11. — Same soil as is shown in Fig. 10. The excessive amount of capillary water prevents its crumbling. Pressure fails to crumble the soil. Instead it retains a waxy appearance and consistency.

moisture conditions, the seed-bed can be perfected in the shortest possible time, and with the least labor. There is

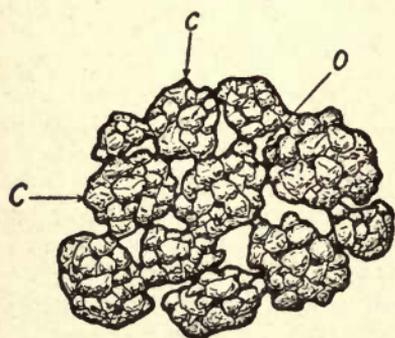


FIG. 12. — Illustrating soil crumbs. *C*, soil crumbs consisting of soil particles held in mass by capillary film. *O*, openings between the crumbs.

an absence of lumps; the soil feels soft and is crumbly. These crumbs are not soil grains, as they are sometimes supposed to be, but rather masses of grains, or particles, held together somewhat as is the corn in a popcorn ball. The chief difference is that in the case of the soil crumbs, the particles are held together chiefly by a film of capillary water. (See Fig. 12.) If

there had been too much water at plowing, the soil particles would have been rolled closer together by the action of the plow. With the correct amount of capillary water,

the particles were first loosened by being rolled over each other, and then rolled into crumbs to be held together by films of water. If the soil had been over-dry, the plow could not have caused the soil particles to separate and be re-crumbed. (Compare Figs. 19 and 20.)

49. Sources of soil heat. — The sun is the great source of heat, and its heat comes to the earth as radiant energy. A part of the sun's heat is intercepted by clouds and other air moisture; a part of it is thrown back into the atmosphere from the earth's surface. Some heat comes from the interior of the earth and, under certain conditions, plays an important part in the behavior of soils.

50. Capillary water and soil temperature. — Mention has already been made of the importance of heat in crop-growing, and reference has been made to Table IV showing the average temperature of soils in different localities for the growing months. Capillary water plays a large and important part in modifying soil temperatures.

51. Specific heat of soils. — The amount of heat required to raise the temperature of a pound of soil one degree, as compared with the amount of heat required to raise the temperature of a pound of water one degree, is called the specific heat of that soil. The specific heat is more concisely defined as the "number of calories needed to raise one gram of a substance 1° C." Here, however, metric units are used, though the specific heat values obtained will be the same.

Bouyoucos, working with Michigan soils,¹ found :

The specific heat of sand to be .1929.

The specific heat of clay to be .2059 approximately $\frac{1}{5}$.

¹ Page 495, Report of Michigan State Board of Agriculture, 1913.

The specific heat of loam to be .2154.

The specific heat of peat to be .2525.

The specific heat of water is 1.0000.

Roughly, the dry sand, dry clay, and dry loam require one-fifth as much heat to warm a given weight of them through one degree as does water. The fact is more impressive, usually, when conversely stated: it requires five times as much heat to raise the temperature of a pound of water one degree as to raise the temperature of a pound of these soils one degree.

52. Proper water content for agricultural soils. — Hellriegel found that when soils experimented with contained 50 per cent to 60 per cent of the water they were capable of holding, their moisture condition was best for producing crops. If his findings are accepted, a soil may be said to be in best moisture condition to support crops when it contains a trifle over 50 per cent of the water it would be holding if all of the space between its soil grains were full. For sandy soils this will not be far from 15 per cent of their own dry weight; for loams, about 20 per cent; for clays, about 30 per cent; and for the finer clays, perhaps as much as 35 per cent. These amounts should be kept constant during the germinating and growing periods of the crop.

53. Effect of water on soil temperature. — For loams, the best quantity of water for crop production is near 20 per cent, or one-fifth of the dry weight of the soil. Thus an amount of loam soil that would weigh 100 pounds dry, should carry 20 pounds of capillary water, and with this water would weigh 120 pounds. One hundred pounds of water requires five times as much heat to raise its temperature one degree as does 100 pounds of soil. Twenty pounds of water requires just the same amount of heat to raise its temperature one degree as does the 100 pounds

of loam which it would properly moisten. In other words, the properly moistened loam requires just twice as much

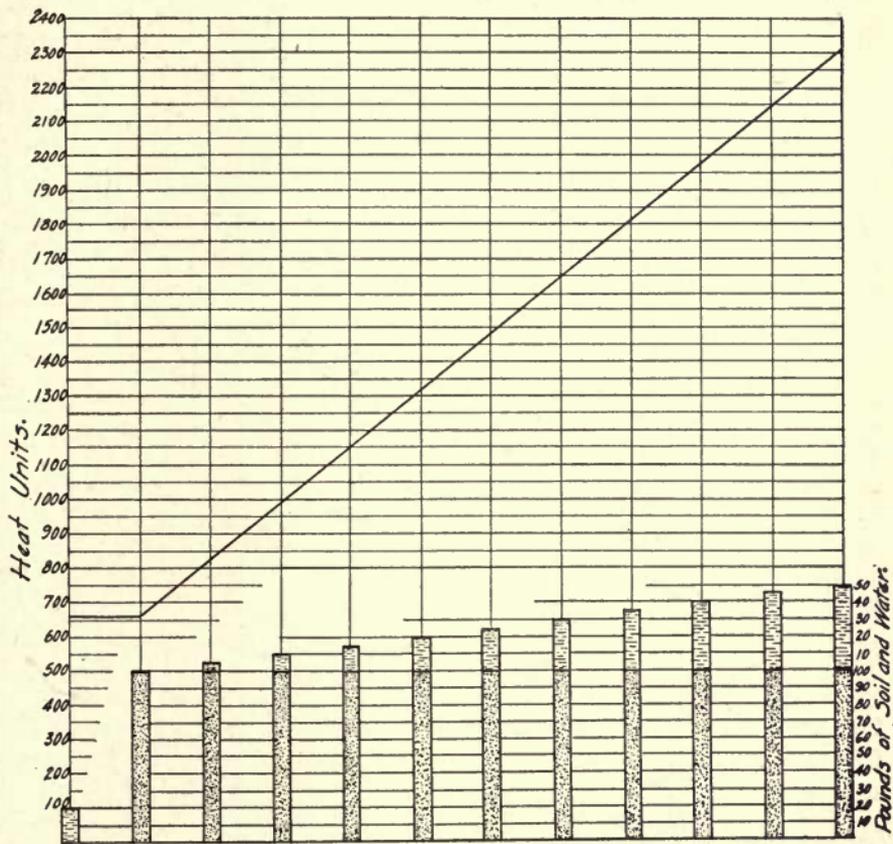


FIG. 13. — Chart indicating diagrammatically the number of English heat units required to raise the amount of water, the amount of dry soil, and the combinations of soil and water, respectively, shown in the lower part of the chart, 33° in temperature ; that is, from 32° F. to 65° F. 65° F. is the minimum desirable temperature for soils for the germination of the seeds of crops. The extreme left column represents 20 lb. of water ; the next, 100 lb. loam soil ; while the others represent 100 lb. of soil with increasing amounts of water. The oblique line indicates the heat units required.

heat to raise its temperature one degree as would the same soil dry.

54. Warm and cold soils. — Since the sands normally carry less capillary water than do the loams, a given amount of heat will raise the temperature of 100 pounds of sandy soil, with its best water content, higher than that of 100 pounds of loam. Therefore it is said that the sands are warmer than the loams. (See Fig. 13.)

Since clays normally carry more capillary water than do the loams, a given amount of heat cannot raise the temperature of 100 pounds of clay soil, with its best capillary water content, as high as it will raise the temperature of 100 pounds of loam with its best moisture content. It is said of clay soils, that they are colder than the loams. Examine Figs. 14 and 15.

55. Over-wet soils are cold soils. — When a loam soil carries 30 per cent of water instead of 20 per cent, it has a half more water than it should carry. It will require one-fourth more heat to raise the temperature of 100 pounds of loam and 30 pounds of water one degree, than will be required for 100 pounds of loam, and its 20 pounds of water. The amount of heat required to raise the latter combination ten degrees in temperature, would raise the former combination only eight degrees.

Soils are seldom too warm in temperate climates. They are often too cold because of the presence of undesirable quantities of water. An increase of water in a soil increases the specific heat of the combination; that is, it increases the amount of heat required to raise its temperature one degree.

56. Heat of vaporization. — Wherever evaporation takes place, heat disappears (is rendered latent). This is equally true whether it takes place from the surface of a field, a block of ice, in a steam boiler, or from the moistened finger held above the head for the purpose of detecting

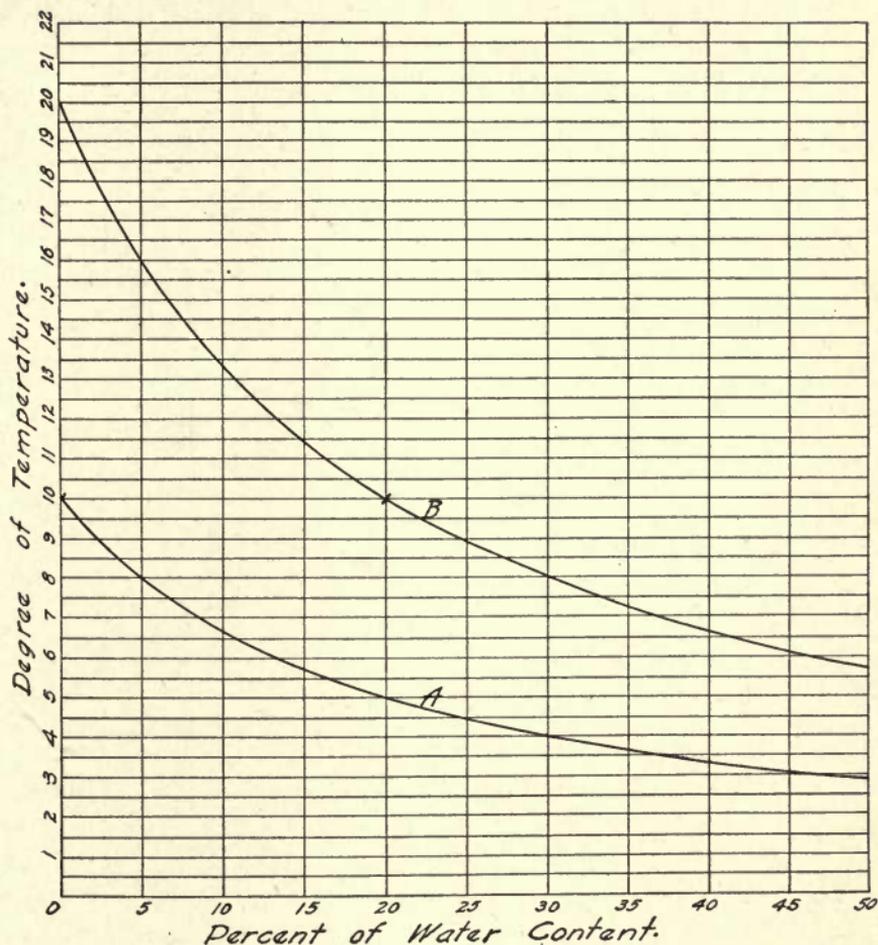


FIG. 14. — Chart showing the effect of a given amount of heat in raising the temperature of soils with different water content. Curve A shows the temperature effect produced by the amount of heat that would raise the temperature of 100 lb. of dry soil 10°. Observe that this amount of heat would raise the same soil with 20 % of water but 5°, and with 50% of water, less than 3°. Curve B shows the temperature effect of the amount of heat that would raise 100 lb. of soil with 20% of water 10°. Observe that if the same soil contained but 15% of water, its temperature would be raised nearly 11½°, but if it contained 40% of water, it would be raised only 6.6°.

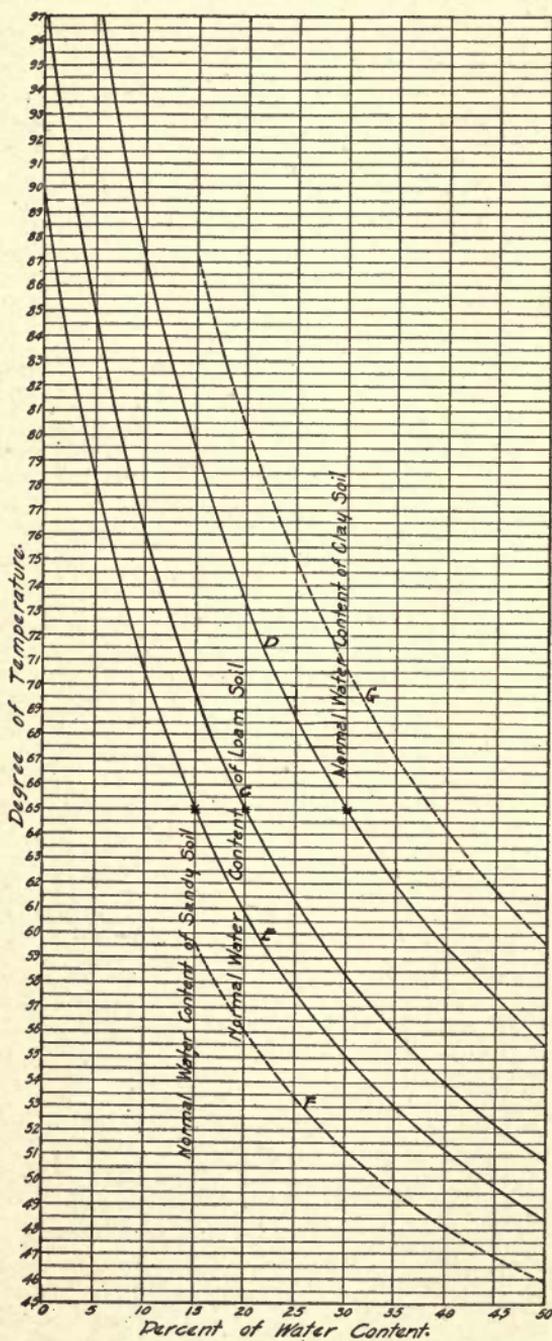


Fig. 15. — Chart showing the temperature effects of the heat required to raise three types of soil with their normal water content from 32° F. to 65° F. of temperature. *E, C, D*, represent the temperature distributions respectively for a sandy, a loam, and a clay soil. The normal water contents of the soils are 15%, 20%, and 30%, respectively. The amounts of heat required to raise 100 lb. of each soil with its normal water content through 33° of temperature are 1155 units, 1350 units, and 1650 units, respectively. Observe, in curve *D*, that the amount of heat that raises the temperature of the clay and its normal water content from 32° to 65° would raise its temperature to 73½° if it carried only 20% water (the amount normal for a loam soil), and to 78.8° if it carried only 15% (the amount normal for sandy soil). Observe also, in curve *C*, that the amount of heat that raises the temperature of the loam soil with its normal water content from 32° to 65° would raise its temperature to but 58.4° if it contained 30% of water (the amount normal for the clay soil). Curve *F* shows the temperature effect upon the first acre-foot of soil that would be produced by the heat required to evaporate 20 tons of water. Curve *G* shows the temperature effect of the same heat applied to the surface 6 inches of the loam soil.

the direction of the wind. The laws controlling evaporation are definite.

The heat apparently disappearing in the evaporation of one pound of water would raise the temperature of 966.6 pounds of water one degree F.

57. A concrete example. — An acre-foot of dry loam soil weighs about 2000 tons. Moisture is continually passing by evaporation from the surface into the atmosphere. Normally, from uncropped, uncultivated surfaces, the rate of this evaporation may amount to 5 to 10 tons an acre in 24 hours. Some condition or mismanagement may readily increase the rate of loss by 2 tons every 24 hours. It is not infrequently increased five times this amount.

In the evaporation of this extra 2 tons of water, enough heat is used to raise the temperature of $(966.6 \times 2 =)$ 1933.2 tons of water one degree. The amount of heat that would raise the temperature of 1933.2 tons of water one degree would raise that of five times that number of tons of dry loam one degree. $1933.2 \text{ tons} \times 5 = 9666.0$ tons.

The heat that would raise the temperature of 9666 tons of loam one degree would raise that of an acre-foot of loam, weighing 2000 tons, $(\frac{9666}{2000} =)$ 4.8333° , and it would raise the acre-foot of loam, with its best capillary water content, one-half of 4.833° , or 2.416° .

The same heat applied to the upper six inches of the acre-foot would raise its temperature $(2.416^\circ \times 2 =)$ 4.832° F.; applied to the upper four inches of the acre-foot, it would raise its temperature $(2.416^\circ \times 3 =)$ 7.248° F. Since the upper soil, being less compact than the lower soils, weighs less to an acre-inch than do the lower soils, the warming of the upper six inches and the

upper four inches would be really greater than these figures show.

These figures are given rather to emphasize the magnitude of the forces involved, and their possibilities when properly directed, than to arrive at absolutely accurate results in practice.

58. Capillary water and ventilation. — Hellriegell found, as has previously been stated, that when a soil contained more than 60 per cent of the water it was capable of holding, the results in crop-growing were not so satisfactory as when the water content was kept between 50 and 60 per cent. The reason offered is that with more than 60 per cent of water present, too little room is left within the soil mass for the proper movement of the air, — for ventilation. Note that with the pore space of the soil half occupied by water, there is left an equal amount of space for the occupation and circulation of air.

INFLUENCE OF SOIL STRUCTURE UPON OTHER PHYSICAL CONDITIONS

While a proper soil structure is greatly dependent on other factors, such as water, organic matter, use of tools, and the like, it in turn becomes a most important factor in the modification and control of other physical conditions.

59. Agencies active in soil ventilation. — Nature employs several agencies by which to cause inward and outward movement of air in the soil, in the process of soil ventilation. The chief agencies concerned in producing these movements are: (1) diffusion, (2) changing soil temperatures, (3) barometric changes, (4) changing wind velocities, and (5) gravitational water. Each of

these agencies is distinctive in its action and might operate alone. All work together, however, and each undoubtedly modifies to some extent the operation of the others; this is especially true of the last-named agency.

60. Relation of soil structure to soil ventilation. — An important part of any system of house ventilation is a capacious set of flues, for both the intake and outlet of air. When the flues are insufficient or when stopped or clogged, the system will fail to do proper work. A soil too compact fails to permit the ready and proper passage, inward and outward, of air. A soil of open structure possesses a greater capacity for air than does a soil of close or compact structure. The structure of the soil, therefore, has a very direct relation to soil ventilation, and observation reveals the fact that crop-life suffers much from improper and insufficient ventilation.

61. Effects of life-forms. — Ventilation is greatly promoted by the burrows of lower animal forms, especially earthworms and ants. These creatures are found in great numbers in soils in which the physical conditions are correct, and burrow to considerable depths. The roots of some plants decompose rather rapidly after the plant has been killed, and thus leave numerous openings or tunnels through the soil. The size of these roots and the depth of penetration depend much on the physical condition of the soil. Every agent active in soil ventilation is assisted by the work of these forms of life in the accomplishment of its function.

62. Influence of soil structure on capillary water. — It is a matter of common observation that of two fields of the same soil formation, the same topography, and the same exposure, one will produce a good crop of corn or wheat in a rather dry year, while the other will produce

only an indifferent crop in a year of ordinary rainfall, and will yield a very poor crop, or may even fail utterly, in a dry year. The reasons for this difference may be very briefly summed up as follows:

The physical structure of the former field is good, that of the latter is poor. When the structure of a soil is good, its capacity to hold capillary water is greater than when

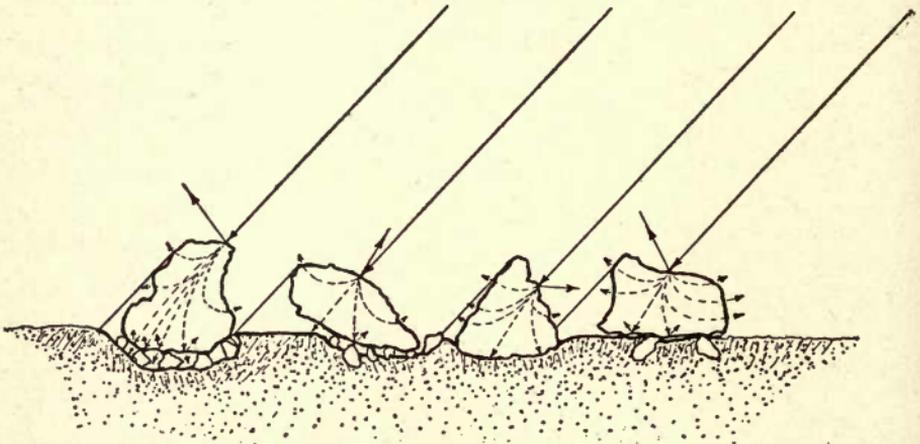


FIG. 16. — The effect of lumps lying on the surface of a field. In all cases the lumps reflect a part of the sun's radiation. Of the radiation which enters the lump, portions are distributed and radiated from the surface of the lump above ground. When the lump rests upon other smaller lumps, leaving air cushions between the lower surface and the soil, other losses occur. That part of the soil surface heavily shaded receives no direct radiation.

it is bad — the storage capacity is greater. The soil of good structure is able to retain its supply of capillary water from evaporation much more successfully than can the soil of poor structure. It offers a much better opportunity for the development of the root system of the crop than does the soil of poor structure. Hence it is that a soil of good physical structure has been known to produce a large crop of wheat without rainfall between planting and harvest, when adjacent fields failed.

63. Influence of soil structure on temperature. — In comparing a soil of good physical structure with one of poor structure, the following facts are offered in favor of the former: it is not subject to such extremes of temperature; it does not cool so rapidly by radiation; it receives more heat from the sun than does a lumpy soil (see Fig. 16); in weather of average rainfall less water evaporates from the soil of good structure, and therefore it is able to utilize more of the sun's heat; it is the warmer soil.

INFLUENCE OF GRAVITATIONAL WATER ON OTHER PHYSICAL CONDITIONS

Mention has already been made of gravitational water, its nature and movements. Its relations to other factors in agriculture and its own individual functions now call for specific attention. In three respects, gravitational water plays a very important part in crop production. In several particulars its extended presence is undesirable, for reasons set forth in this chapter.

64. A replenisher of capillary water. — The water-table is the surface of the water fully occupying the pore space in the soil. It is sometimes spoken of as the surface of the standing water in the soil. It determines the surface of the water in the well. While water will rise in a soil to a considerable height above the water-table by capillarity, the rate of rise and the height to which it will rise are not sufficient to supply the ordinary crops in an average soil. The capillary supply, therefore, must be replenished in another way. It is accomplished by the passage into, or through the soils, of gravitational water. When a rain occurs, the water therefrom passes down into the soil as gravitational water. If the quantity is rela-

tively small, and the capillary supply in the soil has been reduced, it distributes itself, as it moves downward over the walls of the soil particles, as capillary water. If the quantity is large, it distributes itself in the same manner until all the soil particles are fully invested with capillary water, after which any residue moves downward as gravitational water. The capillary supply is thus brought to maximum.

65. Assists in soil ventilation. — One of nature's agents in soil ventilation is gravitational water. This water, entering the soil, fills all the open space, thus driving out the air which previously occupied the open space. As the gravitational water passes downward, fresh air enters to take its place. The operation results in the removal of the air in the soil and replacing it with a supply of new air — a complete change of air.

66. A cleanser of soils. — It is said that in the disintegration of soils, and in the activities of plant life in the soil, there develop certain salts, conventionally spoken of as alkalies, and possibly poisonous by-products of plants, sometimes spoken of as toxines,¹ which, if permitted to accumulate, would work injury to growing crops. In regions of fair rainfall, the frequent passage of gravitational water prevents the accumulation of any injurious salts and, to some extent at least, the poisonous by-products of plants.

67. Standing water or gravitational water in fields destroys soil structure. — It has been previously stated that the crumby condition, so desirable and so characteristic of a mellow soil, is due, in large measure, to the capillary water investing the soil particles, which in turn make up soil crumbs. The outer film of the capillary

¹ Schreiner and Skinner, Bul. 70, Bureau of Soils.

water acts as a membrane holding the particles of the crumbs loosely together. (See Figs. 12, 17, and 18.)

When the pore-space in loam or clay soils is filled with water, as it is when gravitational or surface water is present, the films of capillary water, which may have held the soil in crumbs, can no longer

exist, and the particles, which may have been held in crumbs, proceed to fall apart and then to settle together, as the particles settled to the bottom of the

glass (part 6 of Exp. 5, p. 230), or as when the pyramid collapsed (part 2*b*, Exp. 7, p. 231). Every farmer who has worked clay or loam soils, or observed their behavior, knows what happens when they become saturated with water even for a few hours. No matter how excellent the condition of mellowness may have been, they at once begin to puddle or pack. The longer the saturated condition exists,



FIG. 18. — Pyramid of sandy loam held in position by capillary film. It was formed by pouring a fine steady stream of the soil into a dish in which had been previously placed a small amount of water. As the pouring continued, the water climbed up the mass of soil slowly enough so that the tension of the film held it in place. The pouring was continued till the water was entirely transformed into capillary water. The column stands $2\frac{1}{4}$ inches in height. The column retained its form in an open room several hours after being formed and illustrates the strength of the capillary film.



FIG. 17. — A mass of sand loam held in shape by a capillary film (about twice the natural size).

the more compact the soil becomes, until finally all the mellowing effects brought about by capillary water, tools, roots, and the burrowings of animal forms, are overcome and the mass of soil and subsoil have their pore-space reduced to a minimum, and are left in the poorest possible

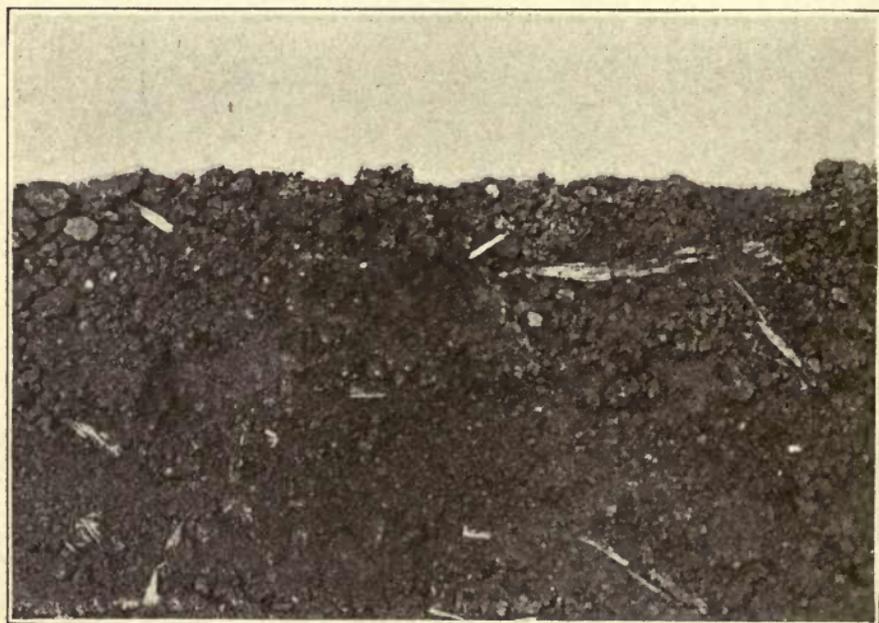


FIG. 19. — The appearance of a recently plowed soil mass when the plowing has been performed with the soil in proper capillary moisture condition.

condition of structure to support plant growth. This is the condition of all soils upon or in which water stands for extended periods.

68. Increased labor required to fit puddled soils for crops. — A soil whose physical condition has been thus compacted by the presence of standing water is subject to more rapid evaporation losses when relieved of its gravitational water. As a result, it is difficult, sometimes impos-

sible, to take advantage of the proper moisture condition for plowing and the consequent partial re-mellowing that might come therefrom. The plow, therefore, leaves the soil in a very lumpy condition. King, in his "The Soil,"¹ gives a very striking illustration of the extra expenditure

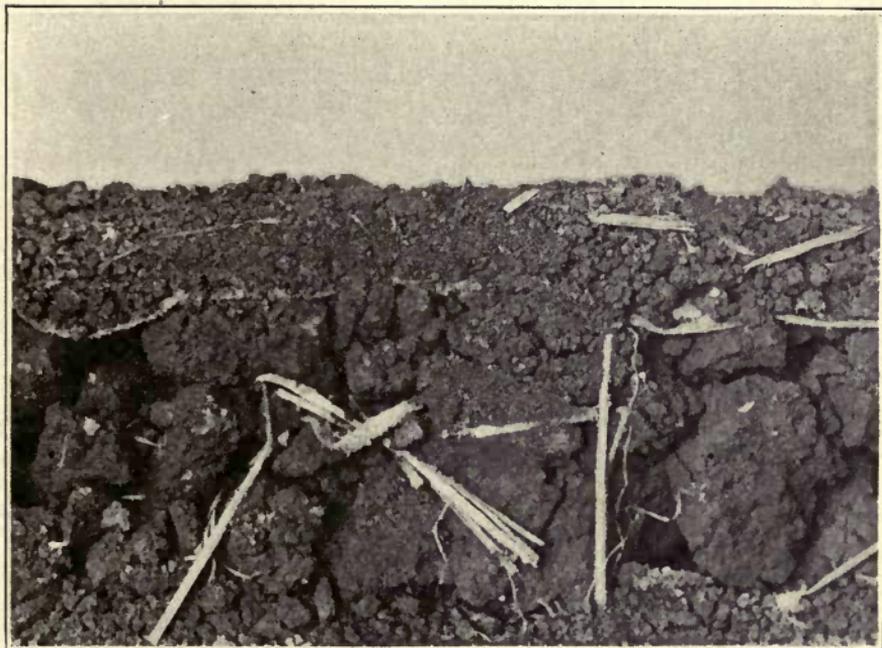


FIG. 20. — The appearance of soil plowed in an overdry condition, and especially after it has been subjected to standing water for some time. The mellowing tools following the plow will produce a zone of mellow soil as shown. They cannot, however, mellow the soil to the bottom of the furrow, and crops planted upon soil in such a condition must fail wholly or in part.

of labor required to develop a proper condition of tilth which, after all, was then only an approximate condition. Complete restoration, even under the less aggravated initial condition which he there describes, was probably impossible for that season. (See Figs. 19 and 20.)

¹ King's *The Soil*, p. 189.

69. Gravitational water may interfere with ventilation.

— The effect of gravitational water upon soil ventilation may be direct or indirect. When water occupies all the pore-space within a soil, practically all air is thereby excluded, — a direct effect. Seeds cannot germinate under such a condition and crops previously occupying the soil quickly die.

Whenever the physical structure of a soil is affected by the presence of gravitational water to the extent of compacting the surface or reducing the pore-space, ventilation is thereby restricted. This restriction of ventilation may be sufficient to interfere with all those processes dependent upon soil ventilation. These effects would be called indirect effects.

70. Gravitational water and food losses. — Gravitational water, as it moves downward through the soil, dissolves and carries away more or less of the soluble plant-foods that have been prepared within the soils. The more slowly gravitational water moves downward, the larger the amount of soluble plant-food it takes with it. The converse is equally true.

Indirectly, the presence of gravitational water causes the destruction and therefore the loss of prepared or partially prepared nitrogen compounds, by the process of denitrification, already described and several times alluded to. Denitrification takes place when air is excluded from the soils.

71. Gravitational water and soil temperature. — The presence of gravitational water in a soil directly affects its temperature in two ways: (1) it increases the amount of heat required to warm the soil; (2) it causes great losses of heat that might otherwise be used in warming the soil. Indirectly, there results to the soil later great

losses of heat because of improper physical conditions resulting from the long-continued presence of gravitational water. (See Fig. 16.)

72. Increased specific heat. — It has already been shown (paragraph 51) that practically five times as much heat is required to raise the temperature of one pound of water one degree, as for one pound of clay or loam soil, and that, therefore, two times the amount of heat is required to raise the temperature of a given weight of soil with a 20 per cent water content one degree as for a soil with no water content. The presence of any amount of water in a soil above the best amount for crop-growing is undesirable. It appropriates heat that would otherwise be used, in part at least, in warming the soil with its proper water content. In Fig. 14 are charted the temperatures to which the same amounts of heat would raise 100 pounds of the same soil but with different water contents. Curve *A* shows the temperature effect of the amount of heat that would raise 100 pounds of the dry loam soil ten degrees in temperature, if the same heat were applied to the same soil with any one of the water contents indicated; curve *B*, that which would raise 100 pounds of soil and its 20 pounds of water content 10° F.; curve *C* (Fig. 15), that which would raise 100 pounds of loam soil with its 20 per cent water content from 32° F. to 65° F.; curve *D* (Fig. 15), that which would raise the temperature of 100 pounds of clay soil with a 30 per cent water content from 32° F. to 65° F.; curve *E* (Fig. 15), that which would raise the temperature of 100 pounds of a sandy soil with its 15 per cent (best) water content from 32° F. to 65° F. The steepnesses of the curves emphasize the meaning of the terms "warm soils" and "cold soils." They emphasize, too, the agricultural importance of preventing the presence,

in the soil, of unnecessary amounts of even capillary water.

As the curves approach that part of the chart indicating a saturated condition of soil, they indicate a very low temperature.

73. Heat lost in the evaporation of gravitational water.— In paragraph 56 it was pointed out that evaporation of water always results in the loss of heat, that the amount of heat used in the evaporation of unit weight of water is constant, and that the heat rendered latent in the evaporation of two tons of water from an acre of soil is sufficient to warm an acre-foot with its normal (20 per cent) content of water 2.416° F.

King and his assistant found that from the uncultivated surface of a sandy loam, placed in cylinders and exposed in an open field for a period of thirty-seven days, losses by evaporation occurred at the rate of 7.24 tons to the acre for twenty-four hours. In this case, the water-table averaged 20 inches below the surface of the soil. The series of experiments of which this was a part showed that the evaporation losses vary with the kind of soil and with the time it has been under cultivation.¹

In the Michigan Agricultural College soil laboratories, in experiments with loam soils repeated through a period of fourteen years, the losses by evaporation from uncultivated surfaces 24 inches above the water-table differed very little from 10 tons to the acre for twenty-four hours.

King concluded, from experiments in the open field, that from very wet soils in April and May, the evaporation losses frequently amount to 28 tons to 33 tons to the

¹ Report Wisconsin Exp. Station, 1898, p. 134.

acre in twenty-four hours.¹ The averages of these losses from very wet soils exceed that from normally moist soil mentioned above, by over 20 tons to the acre for twenty-four hours. In the conversion of this amount of water into vapor, heat was rendered latent sufficient to raise an acre-foot of loam soil, with its normal 20 per cent of capillary water, by 24.16° F. Curve *F* in Fig. 15 shows the temperature effects of the heat here involved if applied to one acre-foot of soil of varying water content, at a temperature of 32° F. When a saturated condition of soil exists through a considerable period, the losses of heat are practically multiplied by the days of the period. It should be borne in mind, however, that if these losses were prevented, not all the heat thus conserved would be stored in the soil; for there are other factors involved that limit the rise of soil temperatures. These factors, nevertheless, would permit a very considerable rise of temperature; indeed they would permit an approximate approach to optimum conditions which cannot take place while such losses occur from evaporation of gravitational water. The figures are given especially to call attention to the tremendous misdirection of the heat supply under the conditions indicated.

74. The effects of gravitational water upon temperature through bad soil structure. — Mention has already been made of the serious extent to which puddling may take place in clay and loam soils that remain, even for a relatively short time, in a saturated condition (paragraphs 67 and 68), and of the effects of such physical condition upon crops planted in such soil, and of the large amount of labor required to reduce the lumpy condition after plowing.

¹ Report Wisc. Exp. Station, 1891, p. 100, and Report Wisc. Exp. Station, 1890, p. 149.

Such attempts at lump reduction are usually only indifferently successful, and the degree of failure is often indicated by the number of lumps lying upon the surface of the field. The writer has found that at 10:00 A.M. on a sunshiny morning in late June, the temperature of a lump-covered soil was 6° F. lower than that of a similar near-by soil in proper tilth, at a depth two inches below the surface in each case. Fig. 16 illustrates how the sun's rays are intercepted as they approach the lump-covered surface and, in considerable degree, reflected and radiated back into the air.

75. The relations of capillary water summarized.— Capillary water is helpful in agriculture. It performs a variety of functions:

- A solvent of foods;
- A carrier of foods,
 - To the plant,
 - Through the plant;
- A food for the plant;
- A factor in soil structure;
- Assists in the preparation of foods;
- Affects temperature of soils;
- Affects ventilation of soils.

In excess:

- It may affect temperature unfavorably;
- It is likely to affect ventilation unfavorably.

76. The relations of gravitational water summarized.— Three helpful functions of gravitational water are:

- To replenish the capillary supply;
- To assist in soil ventilation (in quick passages downward through the soil);

To wash from the soil objectionable salts which, if allowed to accumulate, might do harm to plant life.

Aside from the desirable functions named above, the presence of gravitational water in a soil works harm rather than good, and the list of resulting evils is long and coextensive. The continued presence of gravitational water in a soil:

Destroys soil structure, which results in a number of associated evils, and increases the labor required in preparing the seed-bed, and in performing many of the operations necessary in caring for and harvesting the crop.

Interferes with soil ventilation either directly by partially or wholly occupying the pore-space of the soil, or indirectly by modifying the soil structure. In either case there follows a partial or complete interruption of germination, plant growth, and food preparation. There follows, also, food removal and food destruction.

Reduces temperature, because of the removal of heat from the soil, or the diversion of heat that would otherwise get to the soil. The result here is interruption or prevention of (1) germination, (2) root action, (3) food preparation (chemical, physical, biological). The ultimate result is (1) increased labor, (2) increased inconvenience, (3) decreased yields, and even (4) total failure of crops.

It is evident, therefore, that the presence of gravitational water in agricultural soils, even for moderately extended periods, is undesirable, and that, when necessary, means should be provided to prevent such presence.

DRAINAGE EFFECTS

The steps in soil improvement to be expected from proper tile drainage are summarized in the following paragraphs. They are presented here to bring the facts into perspective.

77. Effects of the permanent removal of standing water.

— It has been shown that no matter how excellent the structure of a soil may be, the excellence cannot be maintained if the soil is subjected for a time to a state of saturation. It has been shown why, and to what an extreme, the packing or puddling may proceed under such adverse moisture conditions. It might seem that where the clay loams and clays have been subjected to the presence of standing water for years, or even throughout the major part of each year for a series of years, the soils would become so compacted as to render it impossible to develop in them the physical conditions so essential to crop production. This, however, is not the case. The rapidity with which these desirable physical conditions develop, after provision has been made for the quick removal of all gravitational or standing water, is frequently surprising.

78. The way in which the changes take place. — When the ground water is permanently lowered to three or four feet below the surface, where previously it stood almost permanently at or near the surface, one of the first effects of the lowering is the development of many cleavages or cracks, such as are seen in Fig. 21. These cleavages occur because of the shrinking of the soil as it gives down the excess of water filling its pore space. This statement may seem to contradict the statement in paragraph 67 concerning the degree to which the pore space is reduced in persistently saturated soils. All saturated

clays, after their pore space has been reduced far below that desirable or necessary to permit the support of crops, shrink when their water content is reduced. The cleavages extend in different directions but at first chiefly vertically. The chief result is that the mass of drying soil is thus reduced to blocks, approximately cubes, in form.

With the next thorough wetting of the soil that occurs because of a heavy rain or melting snow or flooding (for irrigation purposes), these cubes of soil will swell until most of the cracks are closed or nearly so. They will not be closed so tightly, however, but that, as the excess of water causing the

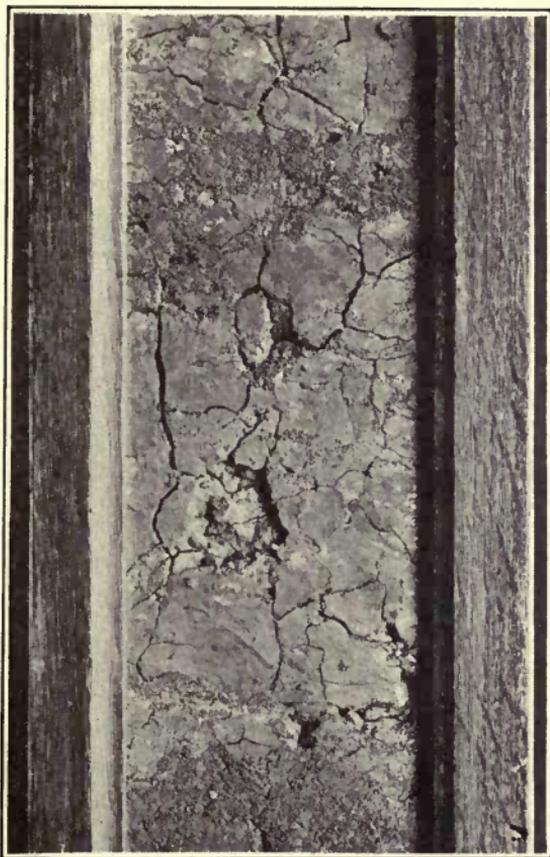


FIG. 21. — A column of heavy clay, showing the cleavages which take place upon air drying. It illustrates the way in which saturated clays check upon the removal of the excess of moisture. It also indicates that this soil would respond readily to tile drainage. With successive wettings and dryings the checking would multiply.

wetting passes downward, these cracks will open again. With this second shrinking, new cleavages occur so that, when this shrinking ceases, the blocks of soil will be

broken into smaller blocks. As succeeding wettings and dryings occur, the subdividing of the masses of soil continues until they become very small.

79. Ventilation plays a part. — As the cleavages in the soil occur, air enters and comes in contact with the soil masses; the degree of ventilation, therefore, is determined by the extent of the cleavaging. The contact of the oxygen of the air with the soil particles in the walls of the masses results in chemical reactions which mean further soil and food preparation. The surface layer is thus made ready to respond to the action of tools in its preparation for the reception of the seed.

80. Other agents. — Crops may now be planted. Their roots, developing, reach outward and downward. Root progress is favored by the crumbling and mellowing already mentioned as having occurred. But these roots, as they progress, wedge apart, disintegrate, and arch the soil particles, with the result that, at the close of the season, the whole soil mass is more mellow and open because of their presence. Then, as they later decay, the chemical products resulting probably cause further soil amelioration.

81. Animal-forms. — The conditions have now become propitious also for various forms of animal life to take up their abode in the soil. Earthworms, ants, and other creatures burrow in the soil, filling it with openings which become passageways for both drainage and ventilation. The materials removed from these passageways, chiefly mineral matter, are deposited upon the surface to be subjected to the direct action of sunshine and air, and to cover the fragments of organic matter already lying upon the surface. Again these creatures, for purposes which may be attributed to them as economic, convey from the

surface to their burrows, great quantities of fragments of organic (chiefly vegetable) material, the greater part of which remains there to become a part of the soil and perform important functions in developing desirable physical conditions. There thus arise various cycles of activities, all of which result in the mellowing, deepening, and perfecting of the soils.

82. Food-preparers. — At the same time there gradually come in and develop such vegetable forms as the nitrifiers and nitrogen fixers, and other food-preparers. In the absence of air they cannot exist; at low temperatures, they work not at all or only feebly. With the mellowing of the soil, opportunity is afforded for the distributing and multiplying of their colonies. With the more complete access of air and increasing temperature, and with the gradual accumulation of organic matter from the decomposition of roots or from the improved condition of the organic matter which may already be present, the activities and products of the nitrifiers and free nitrogen fixers are greatly increased. Moreover, those processes, whether physical, chemical, or biological, by which the mineral foods are prepared, are greatly favored by these same conditions.

83. The final results. — Under adverse conditions evil results seem to be cumulative, and usually really are so. It is equally true that if the removal of undesirable ground water is supplemented with rational practice, the beneficial results are cumulative. As the changes above described take place, every other desirable physical condition is favored. Optimum temperature, optimum ventilation, optimum capillarity are all approached, and all mutually coöperate as is always the case when conditions are correct or favorable.

CHAPTER III

HUMID AREAS AND THEIR RECLAMATION

THERE are large areas, at the present time, unavailable for cropping because of the presence of excessive amounts of water. In the United States they probably aggregate over 135,000 square miles. According to the Department of Agriculture,¹ there are in the United States 79,000,000 acres of land, exclusive of tidal marshes, that cannot be cultivated because of excessive moisture. This aggregate is reclassified in part as follows: 52,665,000 acres continually wet; 6,826,000 acres wet grazing lands; 14,000,000 acres periodically overflowed; 4,766,000 acres farm lands periodically swampy. It is asserted that all of this land could be drained at a net profit of \$1,594,000,000 measured by increase in land values, with an increased annual income of \$273,000,000. They are all called swamp land, and are variously classified.

84. Common swamps. — There are still left some extended areas of flat prairie lands which function imperfectly or negatively, because of the presence of excessive water.

On the Atlantic slope there are some very large fresh-water swamp areas, of which the Dismal Swamp in Virginia is an example. These swamps aggregate many thousand square miles in area.

85. Alluvial plains. — There are considerable areas of alluvial lands liable, at times, to overflow, but at all

¹ Year Book, Dept. of Agriculture, 1912, p. 226.

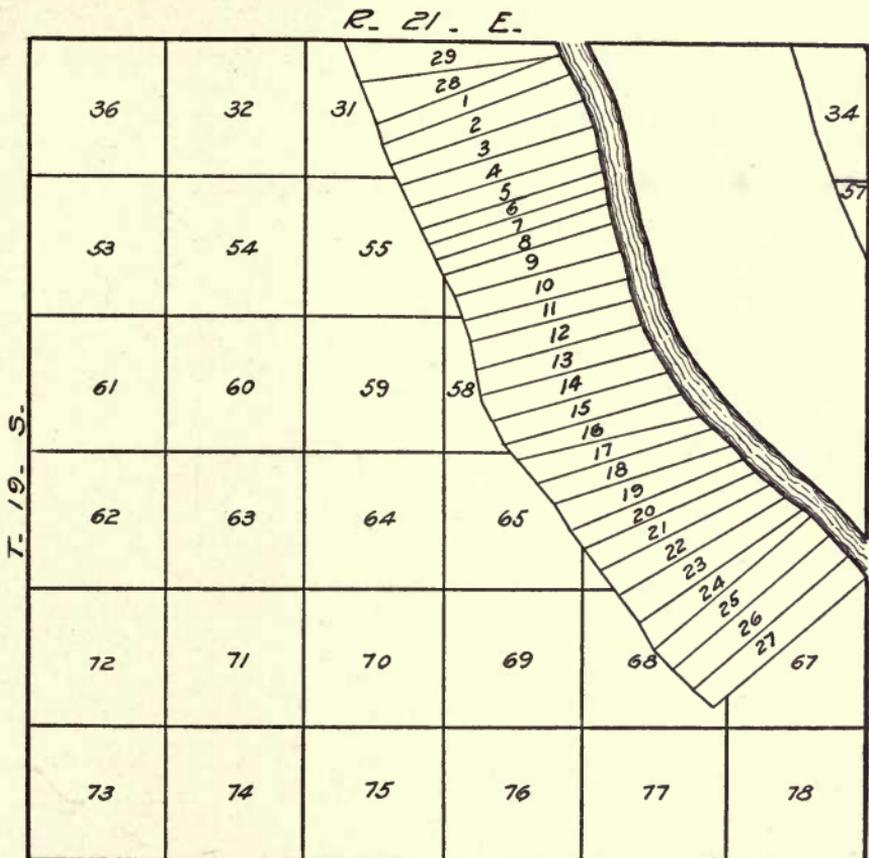


FIG. 22. — Map of Township in La Fourche Parish, Louisiana, showing the way in which the early French Acadians plotted their farms on the naturally drained margins of the rivers and bayous. Back of these parcels of land is marsh.

times subject to freshets because of rains or of melting snow. The fact that, in their lower stretches at least, the surfaces of these plains slope away from their rivers rather than toward them, results in extended flooded areas, at first well back from the river near the edge of the valleys. The areas increase in extent as the outlet of the river is approached, until often the greater part, or all, of the region, excepting a fringe along the stream, is

swamp. This is true of the great Mississippi Delta region. The state of Louisiana has approximately 10,000,000 acres of swamp lands. The map (Fig. 22) shows a section of the Bayou La Fourche, at one time a mouth of the Mississippi, and how the farms of the descendants of the early French Acadians occupy the only naturally drained lands at the time of their coming. The farms are very narrow and lie practically at right angles to the stream. They range from one mile to one-and-a-half miles in length, and touch or include marsh land at their rear. For a distance of forty miles south of Lockport, Louisiana, these farms are said to average less than 250 feet in width.

These alluvial areas are among the richest lands on the globe and are full of agricultural potentiality.

86. Swamps of the drift regions. — Throughout the regions of glacial drift, there are areas of swamp or marshlands, ranging in size from a few square rods to thousands of acres, and even hundreds of square miles. They range in quality of soil from the so-called black ash and cedar swamp, which, while rich in organic matter, contains large quantities of mineral, to deposits of almost pure organic matter, in many cases but slightly decayed. They run in depth from a few inches to many feet. They possess a considerable range of agricultural values, depending upon depth, composition, underlying subsoil, and the like. The soils that have made Kalamazoo, Michigan, famous for the celery sent out to the world, belong to this class, as do also the soils that have made Michigan famous as a producer of peppermint and spearmint oils.¹

¹ Michigan produces 88 per cent of the peppermint oil produced in the United States and 60 per cent of the peppermint oil produced in the world. R. S. Shaw, Spec. Bul. 70, Mich. Agr. Col. Exp. St.

All these marsh soils have been formed under excessive moisture conditions. Their formation, classification, and characteristics are very interesting.¹ Their agricultural value depends finally upon the removal of the excess of water and upon their later management.

87. Marine marshes. — These marshes have been produced by the filling of arms of the sea by dense growths of marine vegetation. To this mass have been added considerable amounts of silt and the shells and skeletons of marine life by the action of the tides. Many of these marshes are very rich and when reclaimed prove very productive. Shaler places the area of the marine marshes of the United States, "including only the deposits which are bared at half tide, and which owe their formation mainly to the growth of grass-like plants," at nearly 10,000 square miles, over 6,000,000 acres.²

88. Reclamation of common swamp lands. — The adaptation of these over-wet areas for agriculture has brought forth numerous and extensive reclamation projects. For many years the drainage of large areas of flat prairies, by extensive open ditch or canal systems, has been in progress in Illinois, Iowa, and other prairie states. One such area in Illinois is known as Vermilion River District. Its main ditch is 10 miles in length, 70 feet wide at bottom and 9 feet deep. In most cases the great main ditches of these prairie drainage enterprises find an outlet by gravity into some natural waterway, such as a stream or river, as is the case with the Vermilion District. In some cases, however, dikes must be built, and pumping stations provided to lift the water out.

¹ See Davis on Peat. — State Dept. of Geology, Mich.

² 12th Annual Report Director U. S. Geological Survey, p. 319.

89. Reclaiming delta lands. — These lands have been built up and are still being added to by the great rivers flowing through them. They are very low, being in many cases only a few feet above sea level. They are lower than the banks of their rivers and in many cases lower than the surface of the rivers at normal flood. Much of the surface of these lands is under water all the year, and in some cases is occupied by shallow lakes. The soil is very deep and rich. In the vicinity of New Orleans, the alluvial deposits are said to reach a depth of 2000 feet. In some parts the surface is covered with grass-like growth, in others by great forests of sycamore timber.

At one time these lands were considered almost worthless for agricultural purposes, and thousands of acres were purchased at a price as low as $12\frac{1}{2}$ cents an acre. At the present time (1915), values have advanced to \$10 to \$30 an acre.

Great drainage projects are already in operation, and others are under way. The method is to inclose a tract of this land by dike, in getting the material for which a ditch of considerable size is excavated inside the dike. The ditch therefore encircles the tract. The area to be thus diked in is selected abutting a natural water course, or some large drainage canal. If it is not so located, it must have a ditch or canal dug to it. The ditch encircling the tract is given a fall such that the bottom is lowest at some point adjacent to the water course or drainage canal. Ditches are next cut across the tract at intervals from the encircling ditch, and again other branches are dug back from these, dividing the tract in units of forty acres or less. All the ditches have such fall that the water in them will gravitate from the smaller to the larger and finally to the lowest point in the encircling ditch.

Upon the dike at the lowest point in the encircling ditch a pumping plant is installed, with a capacity sufficient to lift over the dike and deliver into the water course or outside canal, in twenty-four hours, an amount of water equal to $1\frac{1}{2}$ inches of water over the whole area of the tract.

90. Size of the unit. — These tracts so diked in are called units, and a few years ago comprised about 1000 acres. At this time the unit is considerably larger. Fig. 23 shows a unit containing 1760 acres in process of reclamation.

On February 13, 1915, the pumps

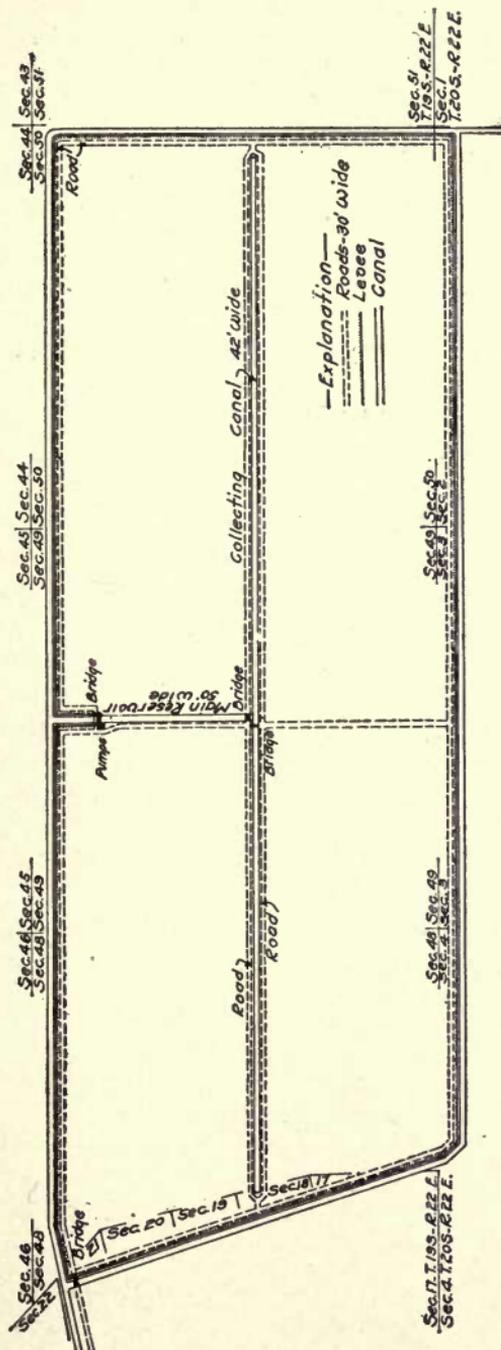


FIG. 23. — A 1760 acre unit diked for reclamation. The location of the main canal in the center, and the surrounding canals are shown, as is also the location of the pumping plant.

were put in operation that will drain a tract of 40,000 acres adjacent to and including a part of the city of New Orleans. There are five of these pumps and together they are said to lift 1,000,000 gallons of water a minute. Such enterprises as this are but the children of those inaugurated by the people of Holland in reclaiming the lands of their country a century ago. The chief difference between parent and child lies in the wonderfully greater efficiency of the centrifugal pumps now used as compared with those used by the Hollanders at the climax of their work. The draining of Harlem Lake in Holland, liberated to agriculture over 44,000 acres of land. The plans for the enterprise were adopted in 1839; the dike was completed in 1843; the actual work of pumping began in May, 1849; the lake was dry in July, 1852. The actual pumping time was nineteen and one-half months and the actual water lifted was over 900,000,000 tons. The ditches were completed in 1856.

91. How the expense of installing, operating and upkeep is met. — When the reclaimed delta lands are sold to farmers, a price to the acre is charged for the land, sufficient to cover the cost of installation. The ditching, diking, and the cost of machinery may frequently be as low as \$25 an acre. Additional tile draining may be found necessary later. The writer has seen large areas of these lands functioning perfectly without drains other than the systems above described.

When a party purchases any number of acres in one of these reclaimed units, he automatically becomes a stock-holder in the drainage plant of the unit, with a vote and a financial responsibility in its operation proportional to the number of acres he owns within the unit.

92. Reclaiming the swamp lands of the drift regions.

— Minnesota is probably leading the other states in the reclamation of swamp lands of drift regions. This is due, in part at least, to the peculiar nature of its drainage laws, and the organization of her drainage commission. Up to the present time, the work of reclamation has consisted chiefly in the construction of large drainage ditches and in the straightening and deepening of the natural water-courses traversing the areas requiring draining.

The Michigan system, which is practically a county system, proves very efficient as a method for accomplishing district drainage.

93. A diked farm in Michigan. — The Owosso Sugar Company's farm, located eighteen miles south of Saginaw, Michigan, is peculiarly situated at the confluence of two considerable sized rivers, and for this reason, and because of the flatness of the country, if unprotected, would be very subject to overflow. The farm consists of 10,000 acres, and is now inclosed by 27 miles of dike, with encircling ditch outside and inside the dike. This dike ranges from 8 to 20 feet in height, and from this fact alone was much more expensive to construct than the dikes of the delta regions. The first "unit" of this farm, opened up, consisted of 4000 acres; and to drain the water from it to one corner, 75 miles of open ditch were dug. The four pumps used in lifting the drainage water over the dike from this 4000 acres have a capacity of 40,000 gallons a minute, 2,400,000 gallons an hour. The open ditches divide the "unit" into 40-acre tracts.

94. Reclaiming marine marsh lands. — The work of reclaiming marine marsh lands, up to the present time in this country, has been accomplished by diking out the sea and digging a system of open ditches. Twenty-five

years ago the drainage waters were removed by gravity through sluice gates in the dike opened at low tide. The shrinkage of these marine marsh soils is considerable, and it is probably only a matter of time when pumping systems for removing the drainage water must replace the gravity systems already installed.¹ The rate at which the saline materials disappear from these soils, after an effective drainage system is installed, is rapid. Shaler says, "These changes will spontaneously take place in the course of 3 to 5 years after the sea is excluded from the marsh, but by breaking up the surface with a plow and cutting frequent ditches through the plain, a single year will often suffice to bring the soil into the state where any of our domesticated plants will grow upon it."²

95. Economic oversights. — Where large areas of land are wholly or largely submerged or saturated, the necessity for drainage is apparent, and effective reclamation methods are applied. The land is thus brought at once to a rather high degree of agricultural efficiency. But there are at least two classes of soils whose service is partially or wholly lost to actual crop production.

96. Areas of imperfect natural drainage. — The first class includes a large number of areas of soil, ranging in size from a fraction of an acre to many acres, which are saturated or submerged a sufficient period each year seriously to affect the physical structure of the soils, and therefore directly, or indirectly, to affect all their other important physical conditions — temperature, ventilation, and capillary moisture capacity. The over-wet conditions usually occur in the spring and thus interfere with

¹ Bulletin 240, Office of Experiment Stations, U. S. Department of Agriculture.

² Shaler, 12th Report U. S. Geological Survey, Part 1, p. 321.

the work of preparing the soil for the crop. The labor of preparation is usually increased, and the planting delayed. The results of the delayed seeding and the injured physical conditions are: (1) reduced yields of crops; (2) increased labor in handling the crops; and (3) again increased labor in the later preparation of the soil for succeeding crops. Instead of net profits, there are realized net losses. The fact that these soils produce "crops" is the chief reason why their owners do not resort to artificial means for preventing the continued presence of saturating water in them. The prevention of standing water would mean net profits instead of net losses from the crops produced. Elevation is not always a factor in the natural control of the water in these soils.

97. Small wet areas. — The second class includes a large number of small areas, perennially covered or filled with water. These areas comprise small shallow ponds; small muck lands, sometimes producing cattails only; small springy areas sometimes on low grounds, and sometimes well up on a slope; small bog lands with streams flowing through them. Sometimes one or more of these tracts lie within a cultivated field, interfering with practically every agricultural operation performed. Sometimes they lie apart, fenced out from the field. Sometimes, when they are fenced out, they have with them a portion of good ground set off in squaring up the field from which they are fenced. Their presence (1) means waste, direct or indirect, (2) lessens the attractiveness of the farm, (3) lowers its value an acre, and (4) may prove a menace to the lives of the animals on the place, and the health of the owner and his family. They remain undrained because (1) their owners become used to them, (2) of their small area, and therefore small direct value,

(3) of lack of understanding how to undertake the work of reclamation.

98. Proportion of waste land. — It is not possible, with the data gathered at the present time, to estimate the ratio which the imperfectly functioning soils of the first class, or which the negatively functioning soils of the second class, bears to the total arable lands of the country. In some parts of the country, it is very large, and there are few portions of humid regions where these areas are not in evidence. The economic losses due to their presence are not appreciated. Neither are the ease of their reclamation, nor their possibilities in crop production, when so reclaimed. It is the existence of these areas and the economic losses therefrom that have prompted the preparation of this volume.

CHAPTER IV

GENERAL DRAINAGE INFORMATION

DRAINAGE may be defined as any artificial means by which the removal of surface or ground water is hastened.

Need for drainage is indicated when water stands at or near the surface of the soil sufficiently long (1) to interfere with farm operations in the way of tillage, planting or harvesting, or (2) to render the soil soggy or compact.

A discussion is hardly necessary to enforce the importance of performing every operation on the farm with promptness and dispatch. If the reader has followed carefully the discussion of the relation of water to agriculture, as set forth on the previous pages, he will understand why soggy or compact soils are undesirable.

99. Lands requiring drainage. — Lands most likely to require drainage fall under one or more of the following heads :

1. Low-lying flat areas, and especially those more or less surrounded by hills.

2. Higher areas of open soil with comparatively slight slopes and underlaid by rather impervious subsoils.

3. Heavy clay soils, even though they have apparently considerable natural surface drainage, but more especially when the surface is marked by slight depressions from which the water cannot drain readily.

4. It frequently happens that in regions generally well drained, there occur small areas underlaid by nearly

impervious strata of clay subsoil. These areas are frequently well up on the sides of slopes, and not infrequently on the top of the highest parts of fields. Such areas may comprise but a few square rods, and yet so persistently is the water held that planting is delayed and, in some cases, actually prevented. Such areas are very common in glacial formations.

5. Springy places that occur at the foot of slopes and not infrequently high up on the sides of slopes.

100. Methods of drainage. — The method to be employed in removing surface water will depend on a number of things, such as: (1) the area to be drained; (2) the nature of the soil; (3) topography; (4) the natural facilities for outlet; and (5) cost of labor and material.

Three methods of drainage are common. They are open ditching, shallow surface drainage and tile drainage, to which may be added a fourth, the use of wells. The latter is sometimes employed in connection with tile draining.

101. Open ditches. — Open ditches are employed in extensive flat countries where the amount of water to be removed is large, and where the fall is slight. In such cases the ditches are often of considerable width and depth, and the nature of the work in laying out and developing such drainage systems is such as to require the training and direction of a professional engineer. After the main ditches have been completed in such systems, it is possible to use tile drainage in the smaller units.

102. Shallow open ditches. — The shallow, open, or surface ditch is employed where the soil is so impervious as to prevent the ready passage of the water downward to drains laid at ordinary depths in tiling, or where natural or artificial outlets cannot be had, or in new sections of

the country. They are sometimes used in conjunction with tile drains, in heavy soils, and especially where the topography is such as to bring the surface drainage into depressions over or adjacent to main tile drains.

103. Tile drainage. — On most upland soils, except in extended flat areas and in occasional cases of impervious soils, tile drainage may be employed and is to be much preferred.

TILE

104. Kinds of tile. — Two general kinds of tile are found on the market: (1) The common porous clay tile and (2) vitrified tile. Vitrified tile, when glazed, as it is sometimes, is often designated as a third kind. Drain tiles are made in lengths of 12 inches and in diameters ranging from 2 inches to 15 inches or more. Tiles less than 3 inches in diameter are seldom used in modern drainage practice. Any saving in cost that may come from using 2-inch tile is more than counterbalanced by its lack in efficiency as compared with 3-inch tile.

105. Common clay tile. — The ordinary clay tile is made of the same material and in much the same way that clay brick are made, and, after burning, possesses much the same texture as the brick made of the same clay. When made of good quality of clay and properly burned, the tile is very durable, and after sixty to seventy years in the soil, if it has been placed below the frost line, shows no evidences of deterioration. If, however, the tile is placed above the frost line, the walls are likely to shale, and in a very short time to collapse.

106. Vitrified tile. — Vitrified tile differs from common tile in two respects: (1) The kind and quality of the material and (2) the degree of heat to which it is sub-

jected in burning. The heat is sufficient partially to fuse or melt the material, and thus to render the walls stronger and much more impervious to water. Vitrified tile, like other kinds, when placed above the frost line, may become filled with water which, in freezing, expands and shatters them. At present, vitrified tile is made not only round, as is the common clay tile, but also in hexagonal shape. It is a question whether hexagonal shapes are desirable, for reasons which will appear when the discussion of the laying of tile is taken up. Note comments in paragraph 109.

107. Cement tile.— Within the past few years the manufacture of cement tile has become common, and numerous machines are to be secured on the market for their manufacture.

108. Difficulties with cement tile.— While much is claimed for the efficiency and durability of cement tile, it has not yet been proved that they may be used successfully even on upland soils. On lowland and muck soils, numerous cases have been observed of their failure to endure. Several instances have come to the writer's attention where, within three months after laying in common muck soils, the cement tile were found to have seriously crumbled and, in many cases, to have collapsed. This may have been due to improper mixing. It did not appear to be due to a lack of richness in cement. The uniformity with which cement tile in muck soil crumbled on the upper surface seemed to indicate that the crumbling was not a mere matter of accident, but rather an indication of the presence of a solvent in the downward moving soil-water. A number of instances are reported in which cement tile have shown a similar crumbling in loam and sandy soils. Patten and Musselman, of the Michigan

Station, recently issued a note to be appended to Special Bulletin 59 of that station, which reads :

“Badly disintegrated tile have been found in muck, sand and sandy loam soils. We have found no satisfactory explanation to account for the trouble, as yet, since tile showing no disintegration have been found in the same types of soil. It may be due to poor construction, insufficient curing, or to the action of the soil and soil solution on the tile.”

Numerous users of cement tile, who enthusiastically champion their use, base their opinion upon several years of experience. Some of these claim even to have used successfully cement tile in muck and bog soils. Elliott, in “Engineering for Farm Drainage,” page 125, says: “Abundant examples of tile now in service prove quite conclusively that well-made cement tile meet every requirement in drainage. Any failure of them indicates imperfections in their manufacture which need not have occurred”; and again, “It is clear that first class Portland cement and good sand should be used and that they should be properly mixed.”

109. Precautions. — The maker of cement tile should observe three things: (1) to use only clean, sharp sand with the cement and gravel; (2) to use a mixture of cement not more lean than 4 to 1; and (3) to exercise care in moistening, tamping or packing. Some of our experiment stations are now making a careful study of the value and durability of cement tile. Elliott says: “In order to obtain a dense, non-porous tile, the mixture should be wet, as opposed to what is known as ‘dry mixture.’ The proportion of 1 part good Portland cement to 3 parts good sand, well mixed, produces a good tile.”¹

¹ Engineering for Land Drainage, p. 125.

On the precautions to be exercised in the choice of drain tile, Fippin writes as follows:¹

“The preëminent material for modern land drainage is tile. It comes in different shapes and quality. By a process of evolution we have come to prefer round or hexagonal tiles because they are easiest to lay and least likely to clog. They may be made of burned clay or of concrete. Clay tile may be either vitrified or unvitrified. The former is the more durable because its walls are less porous. The difference lies in the quality of clay used and the degree of heat applied in burning. Vitrification means partial melting of the clay particles, which run together in a very dense mass. A low degree of porosity coincident with a moderate degree of vitrification is especially desired where the tile is likely to freeze. In the soil the pores in the tile become filled with water, and if it freezes in this condition the walls of the tile may be fractured and broken up into scales. If even one or two tiles in a long line are thus destroyed, the service of the drain is jeopardized. Since vitrified tile costs no more on the average than soft tile, there is no excuse for taking the risk in using the soft tile. The drainage efficiency of the tile is not affected by the difference in the porosity of the walls, since the water enters at the joints.

“Cement tile that are of fairly good quality may be made by hand or in machines. It is doubtful whether they can be made as durable as the best clay tile. They should be carefully made of a rich mixture. Sand that is a little loamy improves the quality, if the mixing is thorough, as it reduces the amount of pore space. Whether cement tile can be made at prices to compete with clay tile depends

¹ Cornell Reading-Courses, iv. No. 78 (1914).

on the size made and on the local situation in labor and materials for the two kinds of tile.

“Only sound tile giving a true ring should be put in the ground. The ends should be reasonably square and smooth, so that a good joint can be made. This is most important when laying tile in soil of a quicksand nature. Here special precautions against clogging are necessary.”

110. How water enters the tile. — There is only one way, in the case of glazed tile, for water to enter and that, of course, is by way of the joints.

In the case of porous tile, in all but the heavier soils, the greater part of the water enters by way of the joints; this is probably true even in the case of the heavy soils.

In the Soils Laboratory of the Michigan Agricultural College, very careful tests showed that in the case of common 6-inch tile, laid 4 rods apart, the rate at which water entered through the walls was 2 tons to the acre in 30 hours, while in the case of 4-inch tile, laid in the same way, the rate was 1.55 tons in 30 hours. A 4-inch tile, of apparently more porous type, laid in the same way, permitted water to flow through the walls at the rate of 1.66 tons to the acre in 30 hours.

In the case of most cement tile, as they are commonly made, water passed through the walls with great readiness. Cement tile was also used in the tests referred to above, and water was found to enter through the wall of 4-inch cement tile, laid in the same manner and under the same conditions as the common tile, at the rate of 1224 tons to the acre in 30 hours. This is equivalent to over 8.6 acre inches in 24 hours.¹ The readiness with which water passes through the walls of the cement tile, as ordinarily

¹ Special Bulletin 56, Mich. Agr. College Experiment Station, p. 5.

made, may be easily observed if one will hold a tile so that one can see along the inner surface and then slowly pour water upon the upper outer surface. It requires but a few seconds for the water to pass through and hang in large drops on the inside of the tile. In heavy soils, a tile possessing the porosity of the cement is greatly to be desired. Undoubtedly Elliott would disapprove of the use of cement tile of so open structure.

111. Tile systems. — In the draining of a piece of land, there are several things that should be carefully considered. It may be that a single line of tile will be sufficient to remove the surplus water from the area to be drained. This is likely to be the case if the area is not over 100 to 150 feet wide, provided the soil is relatively open. If the width is greater than 150 feet, or if it is as little as 100 feet, with a relatively impervious soil, it is probable that more than one line of tile will be required. If the one line is not sufficient, then a system should be introduced, the style of which will depend upon the surface and shape of the area and, possibly, on the notion of the one who is installing the system.

Two general systems employed in tile drainage are illustrated in Figs. 24, 25, 26. All kinds of combinations of these are found in actual practice. (See Figs. 27, 28, and 29.) In any system of tile, that line which receives the water from all the other parts of the system is called the main, and all the lines receiving the water directly from the soil and conveying it to a main are called laterals. If there should be more than one system of laterals, each system flowing into another line than the main, which in turn carries the water to the main, each of these lines is called a sub-main. Figures 27 and 28 illustrate this point.

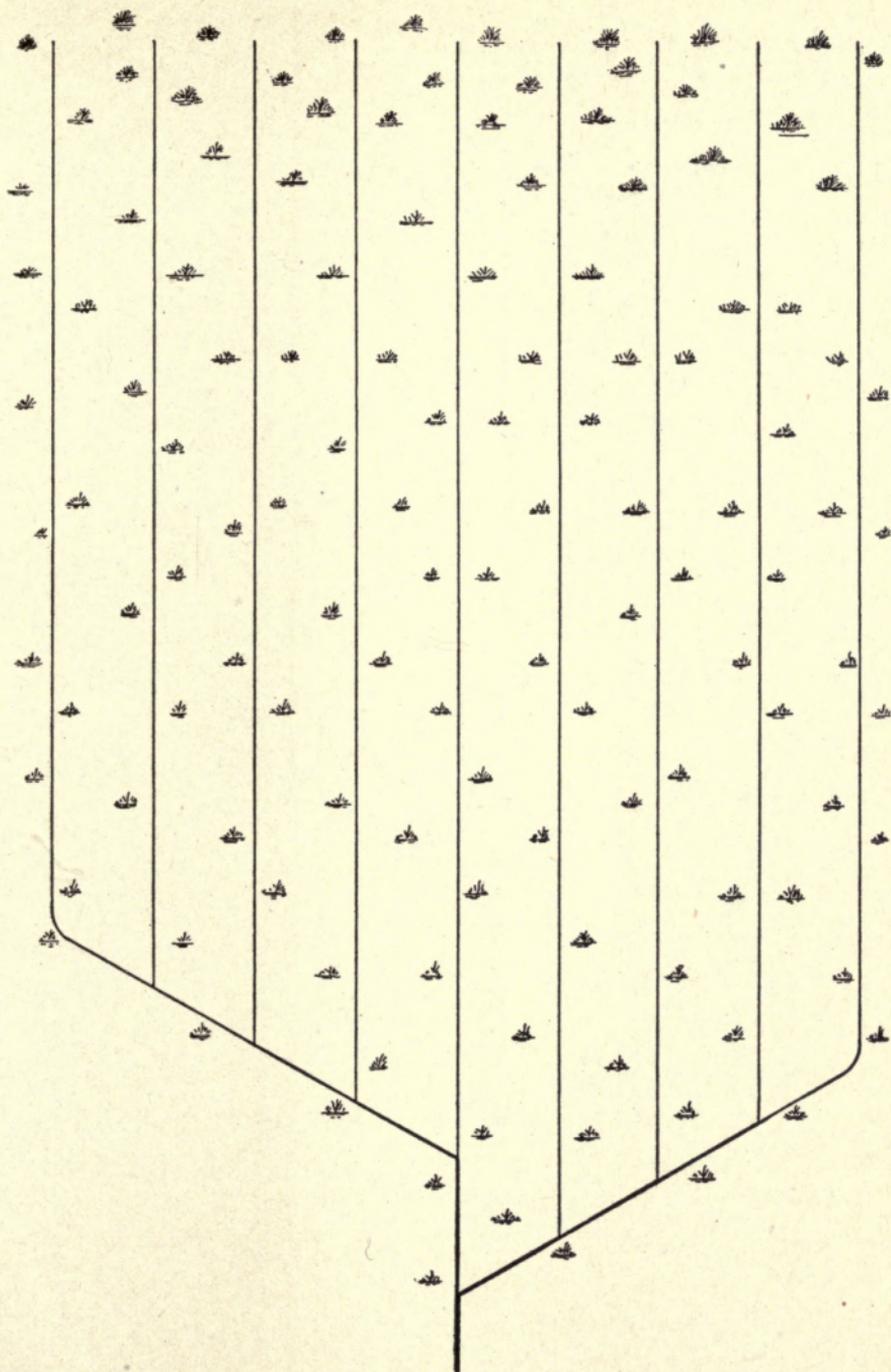


FIG. 24. — A system of parallel drains.

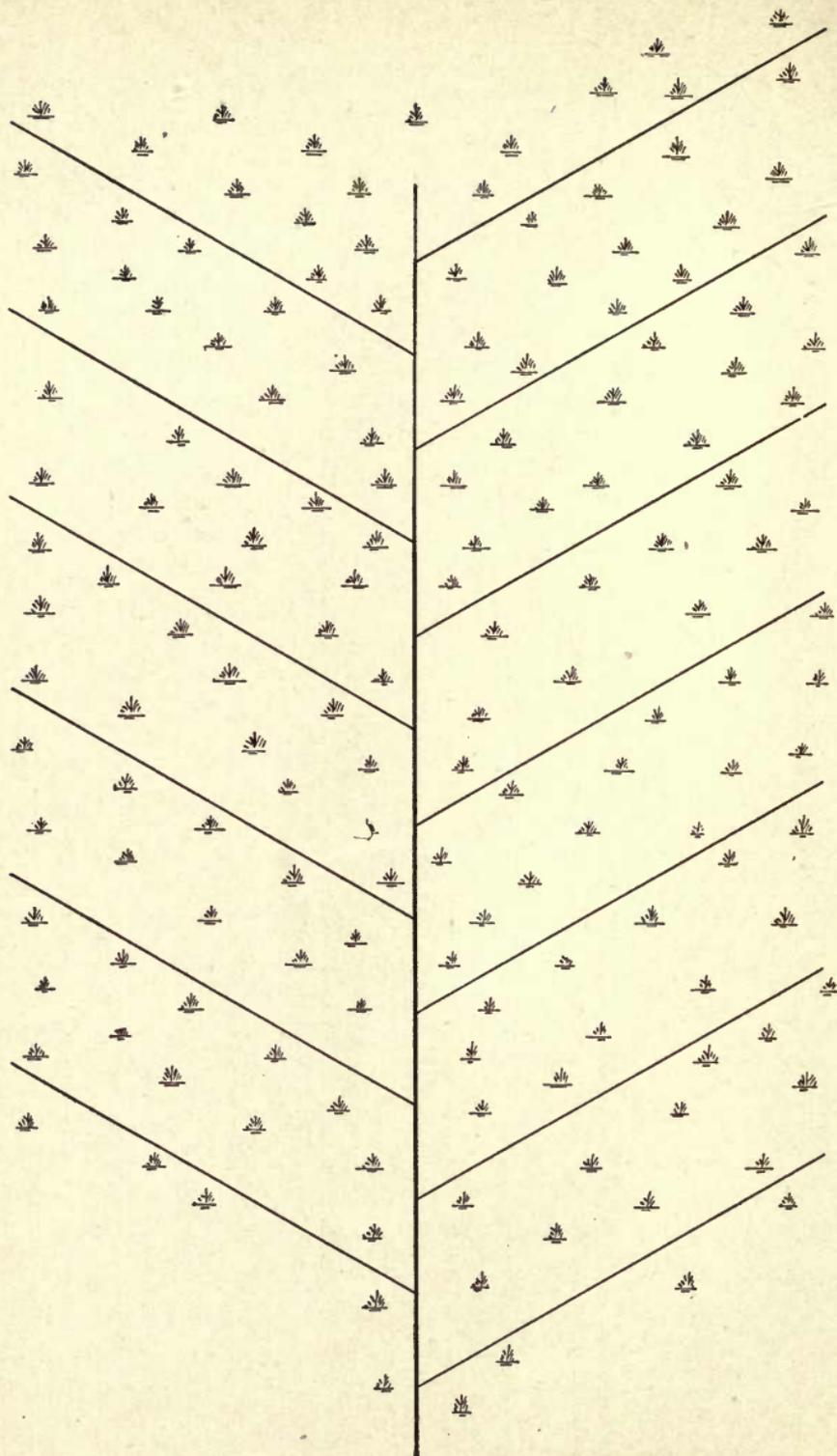


FIG. 25. — A system comprising a main, and laterals approaching obliquely.

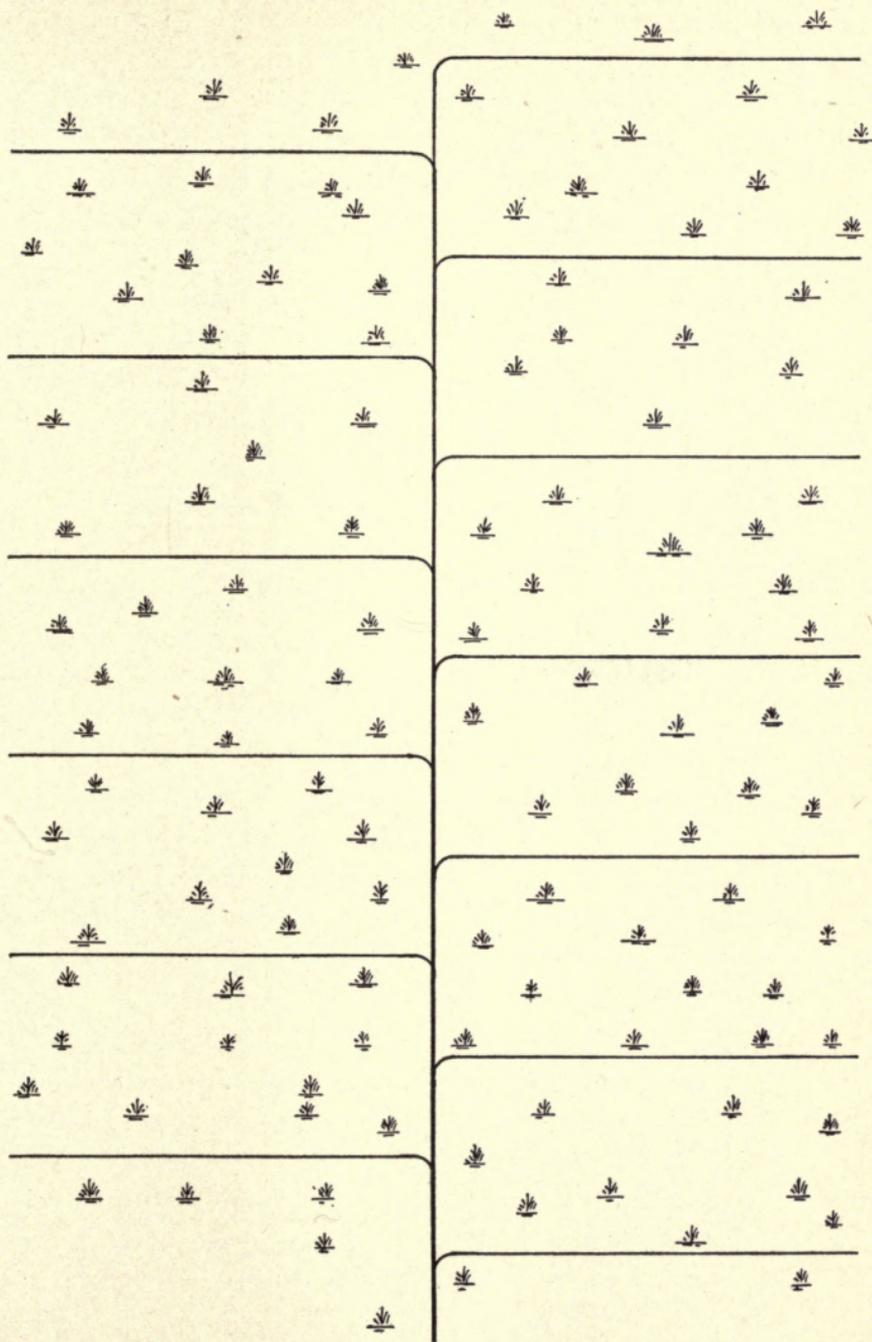
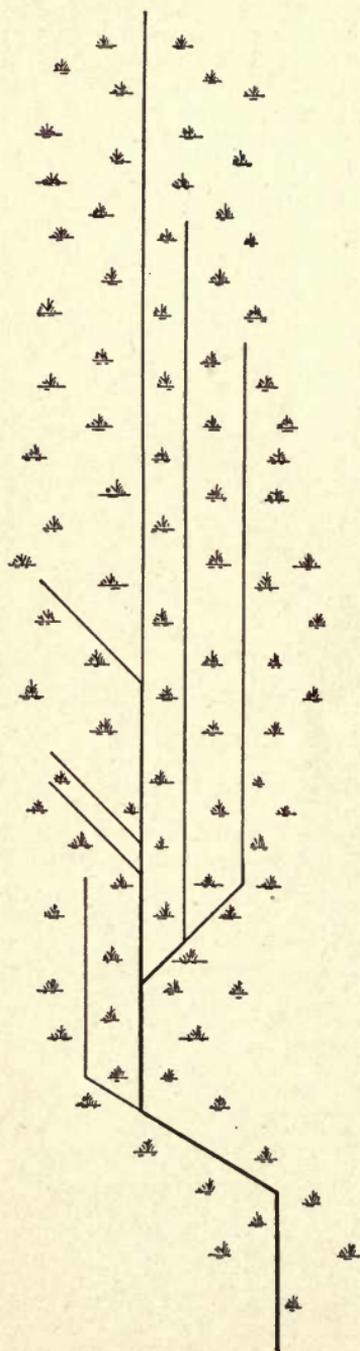


FIG. 26. — A system in which the laterals are laid at right angles to the main.



112. Outlet. — The point at which the main discharges its water is called the outlet. The efficiency of a tile system and the expense of installing will depend very much on the location and construction of the outlet. The outlet may discharge its water into any natural water-way or stream, ravine or drainage ditch. Generally it should be so located that the main shall extend through the lowest portion of the area to be drained, and so that it may be placed with the least amount of digging and have the fewest possible angles in its course. This outlet should be so situated that the ordinary outside water should not stand as high as the bottom of the tile.

113. Depth of tile drain. — It is desirable that tile drains shall lie, generally, not less than three feet below the surface. Occasionally a farmer is met who believes that tile drains should be laid as deep as four feet. Waring favored a depth of four feet. According to Elliott, 4 to $4\frac{1}{4}$ feet is deep, 3 feet is

FIG. 27. — A combination of the systems shown in Figs. 24 and 25.

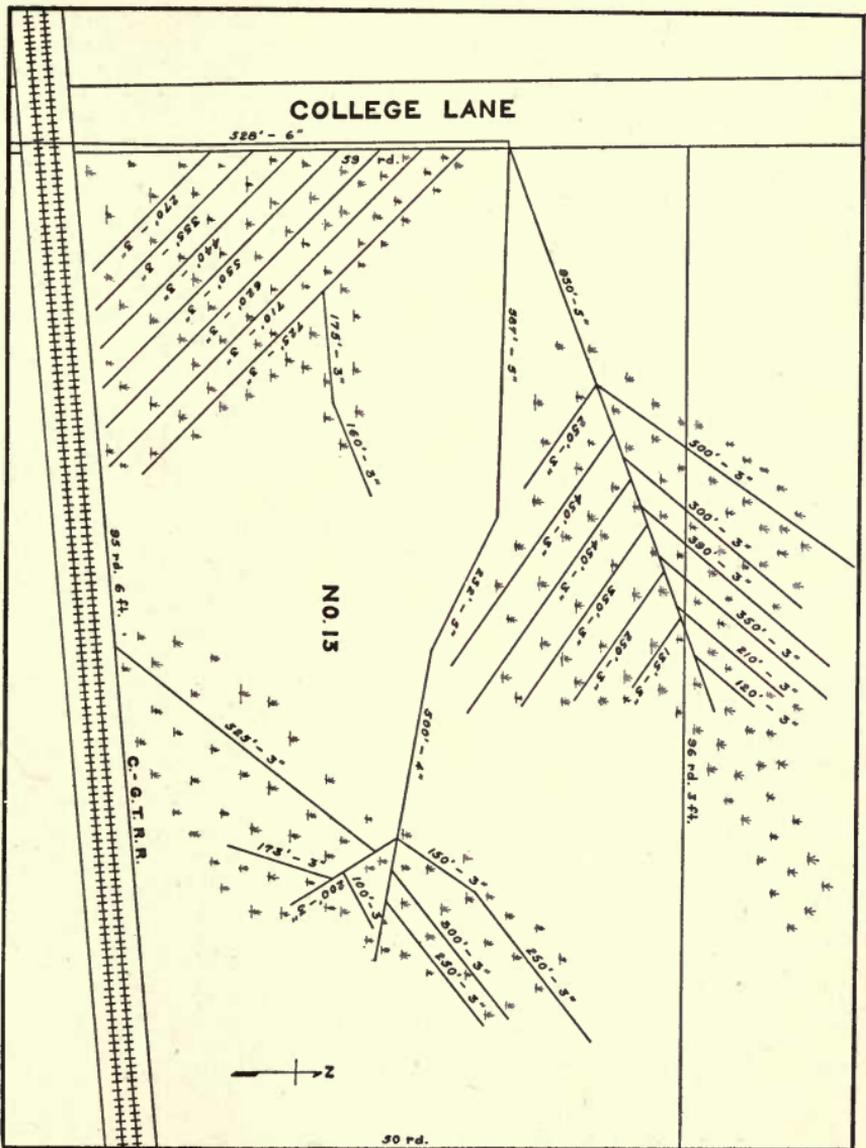


FIG. 28. — A system which has been in operation for a number of years. It conforms in plan and efficiency to the requirements of the topography of the field. The north section, after having been in service some 15 years, was lowered two feet because of the lowering of the surface from shrinkage from various causes.

medium and 2 to $2\frac{1}{2}$ is shallow. It sometimes happens that in fields with uneven surfaces, or where it is difficult to get the proper amount of fall, the tile must be laid in places as close to the surface as 18 inches. Tile placed too near the surface are subject to freezing, and freezing is almost sure to result in the cracking of the tile, or in causing it to shale, which is likely to result in its complete collapse. A depth of less than 3 feet fails to give to the roots of most crops a sufficient amount of room for development and forage. Greater depth than 3 feet increases the effectiveness of drainage. The champions of deep laying of tile offer three reasons for the practice: (1) root room, (2) capillary water supply, (3) food development.

114. The distance apart of tile drains. — There is a rather close relation between the depths to which the tile are laid and the distance that may exist between tile lines. Other things being equal, according to common theory, the deeper the drains are placed, the greater the distance that may lie between them, and *vice versa*. The largest factor, however, in determining the distance apart of drain lines is the character of the soil.

In very heavy clays, it may be necessary to place tile drains not over 30 feet apart, while in very open soils they may be placed as far as 150 to 200 feet or more apart. In muck soils they may be placed from 60 to 80 feet apart, and in ordinary loams 70 to 100 feet. Eighty-five feet apart is probably a fair average.

Where soil is underlaid with a heavier subsoil, lying so near the surface that the tile must be set down into it, the drains must be placed closer together than would be necessary if the subsoil more nearly resembled the soil above in openness. (See Fig. 30.)

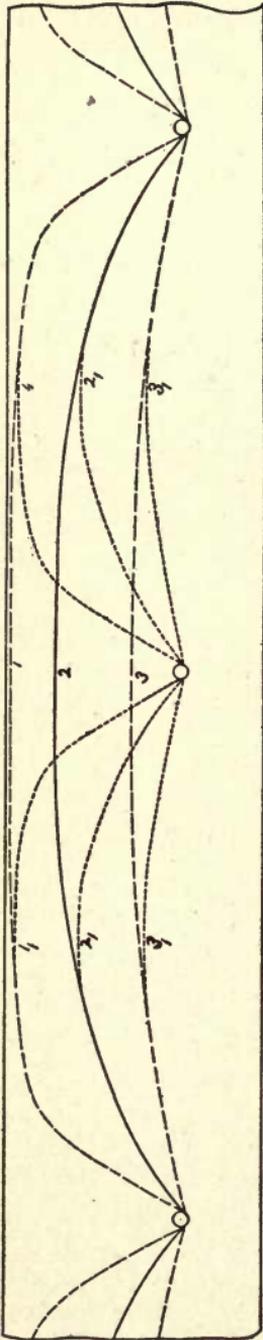


Fig. 30. — Showing the way in which the water table is changed by the insertion of the tile midway between two others. Curves 1, 2, and 3 represent the water tables at different periods after saturation.

115. How water approaches the tile drains.—In approaching drains, the ground water undoubtedly moves in such a way as to reach the drain by lines of least resistance. When a heavy soil is underlaid by a porous or sandy soil at or near the plane of the tile, the water will meet less resistance by following paths indicated by the arrows in Fig. 31. If, however, the heavy soil extended a foot or more below the plane of the tile, the water would undoubtedly move toward the tile in lines much more direct.

Water will not enter a tile when no part of the surface of its zone of saturation lies higher than the bottom of the tile. In other words, water will not enter a tile drain except by its own gravity or when forced toward the drain by some pressure exterior to itself.

116. Size of tile to use.— Ordinary drain tile ranges in size from 2 inches in diameter up to 12 and even 15 inches. The capacity of different sizes of tile to carry water, with rate of flow constant, varies as to the square of their diameters. The square

of the diameter is the product of the diameter multiplied by itself. When water in them has the same rate of flow, 3-inch tile will carry $2\frac{1}{4}$ times as much water, as will 2-inch tile. To illustrate: $3 \times 3 = 9$, $2 \times 2 = 4$; 9 is $2\frac{1}{4}$ times 4; $2\frac{1}{4}$ represents the relation of the amount of water that will flow through 3-inch tile as compared with the amount of water that will flow through 2-inch tile when they have the same fall. A 5-inch tile will carry $1\frac{9}{16}$ times as much water at the same rate of flow as a 4-inch tile. To illustrate again: the square of 5 is 25, the square of 4 is 16, 25 divided by 16 equals $1\frac{9}{16}$.

The size of tile to be used in any instance will depend on the area from which it is to carry water, and whether it is to carry away only the excess of water due to rainfall on the area, or whether there is added other water brought in by springs, or surface drainage, or seepage from adjacent areas.

It is hardly advisable to use tile so small as 2 inches in diameter. The following gen-

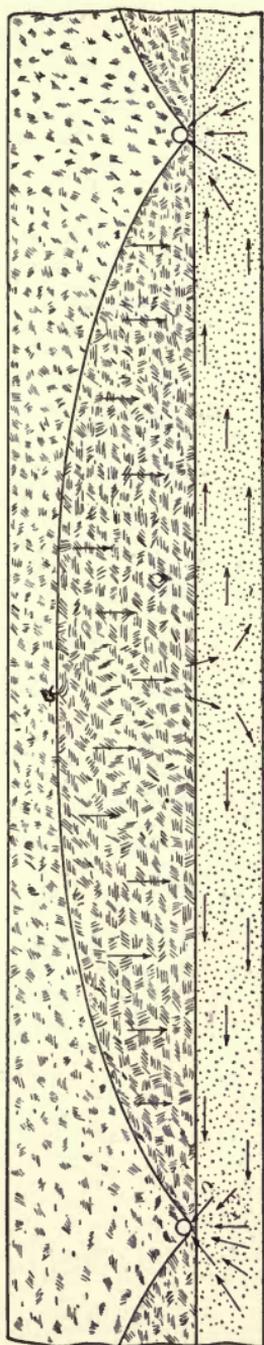


Fig. 31. — Showing how water approaches the tile, when the tiles are laid in a rather heavy soil underlain by a more open subsoil.

eral statements are quoted from C. G. Elliott, recognized as one of the foremost drainage engineers in this country. These statements apply to average conditions:

“When drains are laid so that there shall be a fall of 3 inches in 100 feet, a 3-inch tile will drain 5 acres, and should not be of greater length than 1000 feet.

TABLE VI

RELATION OF SIZE OF TILE AND FALL TO CAPACITY TO CONVEY WATER

WITH A FALL OF	3"	2"	1"
A 4-inch tile will drain	14.5 A.	12.8 A.	11 A.
A 5-inch tile will drain	25 A.	22 A.	19 A.
A 6-inch tile will drain	39.6 A.	34.8 A.	30.0 A.
A 7-inch tile will drain	58 A.	51 A.	44 A.
An 8-inch tile will drain	80 A.	71 A.	61 A.

“These are maximum capacities where the drain does not exceed 1000 feet in length.

“A long drain has a less carrying capacity than a short drain of the same size laid upon the same grade.”

It is not difficult to see that if a long drain is to be laid, and especially if this drain is a main receiving water from laterals or other sub-mains, it will be necessary, from time to time, to increase the size of the tile laid as the drain approaches the outlet. Fig. 32 illustrates this point.

By giving careful attention to the capacity of the various sizes, it is possible to exercise considerable economy in the use of tile laid in any system.

The tendency of the day, according to Fippin, is to increase rather than decrease the minimum size of the

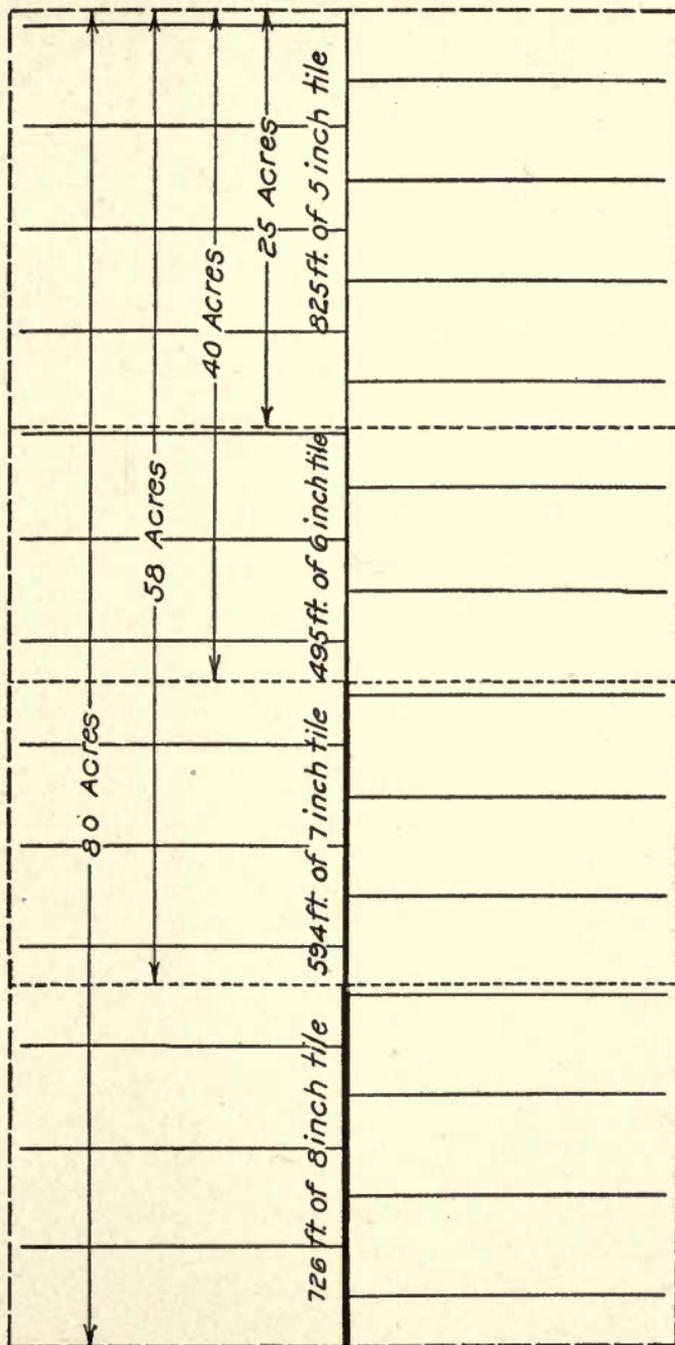


FIG. 32. — To illustrate Table VI. The 726-foot section of 8-inch tile has a capacity sufficient to carry the water delivered by its own laterals and also that delivered from the field above. The 594-foot section of 7-inch tile has a capacity sufficient to carry the water delivered by its own laterals and that delivered to it from the remaining portions of the 58 acres above. A part of the 825-foot section of 5-inch tile might have been laid in 4-inch. 4-inch tile is sometimes used for mains.

tile used. "From the minimum size the tile will increase in size according to the extent of the system. It is now not uncommon for tile as large as two feet in diameter to be used. Three-inch tile in lines not more than six hundred feet long are usually best for lateral drains. For drains up to fifteen hundred feet in length, four-inch tile may be used, provided the grade is not less than four inches per hundred feet. It is difficult to make an exact statement concerning the proper size of main drains. In general they should be capable of removing one-fourth of an inch of water from the drainage area in twenty-four hours."

117. Grade or fall. — Every line of tile should be so laid that there is a gradual fall from the extreme end of the drain to the outlet. This fall is usually spoken of as the grade. It is desirable, when possible, to have a fall of as much as 3 inches in every 100 feet. A carefully constructed line of tile will work successfully on a much less fall than this. Two inches is a common grade, and in very flat areas a fall as slight as 1 inch to the hundred feet is used; and occasionally a fall of $\frac{1}{2}$ inch to the hundred feet for tile as large as 8 inches.

118. Relation of size of tile to the grade. — The less the fall, the greater must be the care exercised in laying the tile, and the less will be its capacity to remove the water and therefore the larger must be the tile. Elliott says: "If we double the grade per hundred feet of the drain we increase its carrying capacity about one-third." If this be true, then if we lower the grade by half we should decrease the carrying capacity by one-fourth.

The following figures, from Fippin, give some idea of the area of land drained by some common sizes of tile when laid at different grades:

TABLE VII

NUMBER OF ACRES FROM WHICH ONE FOURTH INCH OF WATER WILL BE REMOVED IN TWENTY-FOUR HOURS BY OUTLET TILE DRAINS OF DIFFERENT DIAMETERS AND DIFFERENT LENGTHS WITH DIFFERENT GRADES

DIAMETER OF TILE IN INCHES	GRADE IN INCHES PER 100 FEET									
	1		2		3		6		9	
	Length of drain in feet									
	1,000	2,000	1,000	2,000	1,000	2,000	1,000	2,000	1,000	2,000
	Acres of land drained by different sizes of tile									
5 . .	19.1	15.7	22.1	19.4	25.1	22.7	32.0	30.3	37.7	36.3
6 . .	29.9	24.8	34.8	30.5	39.6	35.9	30.5	47.8	59.4	57.3
7 . .	44.1	36.4	31.1	44.8	58.0	52.8	74.0	70.1	87.1	84.1
8 . .	61.4	50.7	71.2	62.6	80.9	73.6	103.3	98.0	121.4	117.3
9 . .	82.2	68.1	95.3	83.8	108.4	89.6	138.1	131.3	162.6	157.1
10 . .	106.7	88.5	123.9	108.9	140.6	128.1	179.2	170.5	211.1	204.4

119. Uniformity of grade. — It is desirable to have the grade uniform throughout the length of each line of tile. This is not always possible for reasons which will appear later. When changes in grade must be made, it is still desirable to make them as few as possible, and to keep the grade uniform in as large sections as possible.

There is no objection whatever to changing the grade from any rate of fall to a greater grade, but care must be observed. The water moving through the drain carries with it more or less fine material which has worked its way through the joints of the tile. This material is spoken of as silt. The particles of silt are sometimes so large as to be moved but slowly by the running water in the tile — so slowly indeed that if the rate of flow of the water should be decreased by ever so little, its force will then be insuffi-

cient to continue to move the particles. If, then, in a line of tile the fall were lessened at some point, it might happen that considerable quantities of this silt would accumulate at the point of change. Sometimes this happens to the

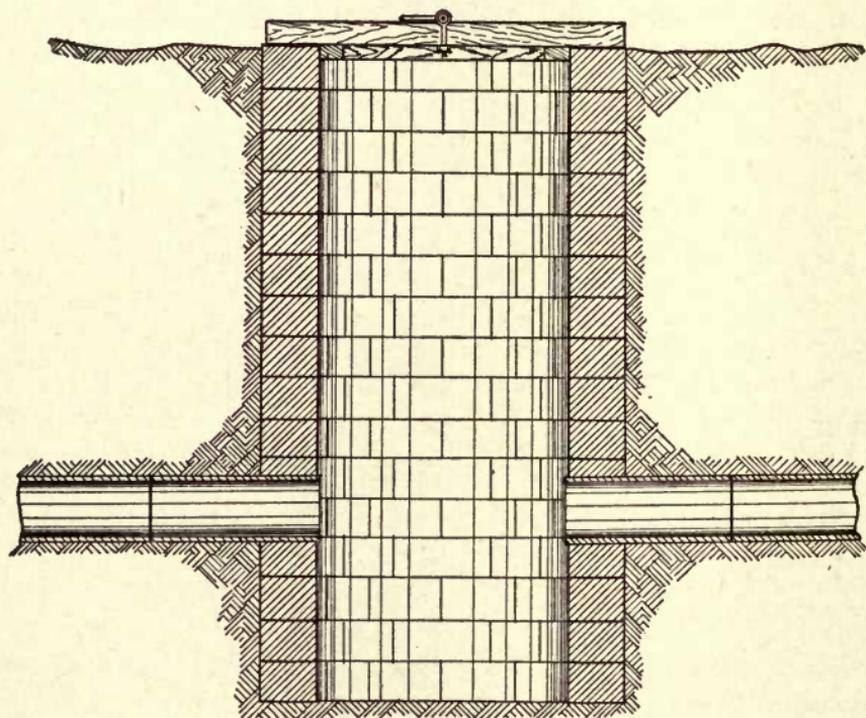


FIG. 33. — Silt-basin built of brick.

extent that the tile is clogged. Means should be provided, therefore, to prevent such a contingency.

120. Silt-basins. — To prevent the clogging of tiles by the accumulation of silt, chambers or openings, such as are illustrated by Figs. 33, 34, and 35, are established at intervals along the tile drain. They are commonly called silt-basins. These are placed wherever in a line of tile the grade is changed from a higher to a lower rate of fall, and especially where it is evident that the

movement of the water below the point of change is likely to be so slow as to find difficulty in moving the particles of silt. They are also placed where a sub-main unites with a main, and where a long lateral unites with a main

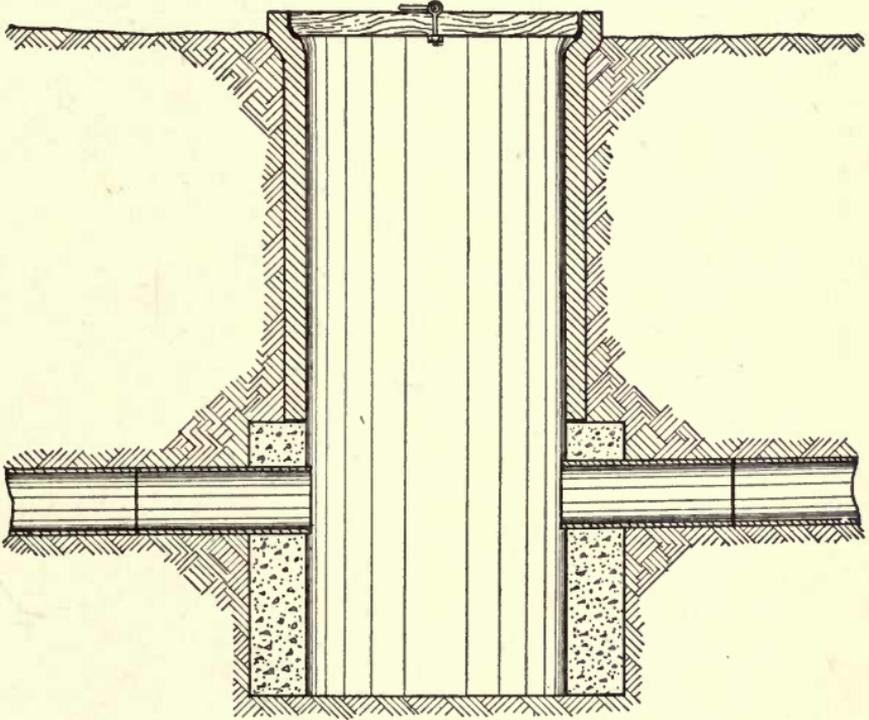


FIG. 34. — Silt-basin of concrete and sewer tile.

or a sub-main, and at intervals along any considerable line of tile, whether it is lateral, sub-main, or main. In the last named case, the purpose is not only to gather the silt moving down the line, but also as a provision for examining the condition of the tile drain. By such a distribution of silt-basins, the line or system is divided into units, and if a mishap, resulting in the clogging of any portion of the system, occurs, the unit in which it is located can usually be established by examining the silt-

basins and noting the flow of the water into and out from them.

121. How the silt-basin performs its work. — The bottom of the silt-basin should stand at least a foot below the lower edge of the tile running from the basin.

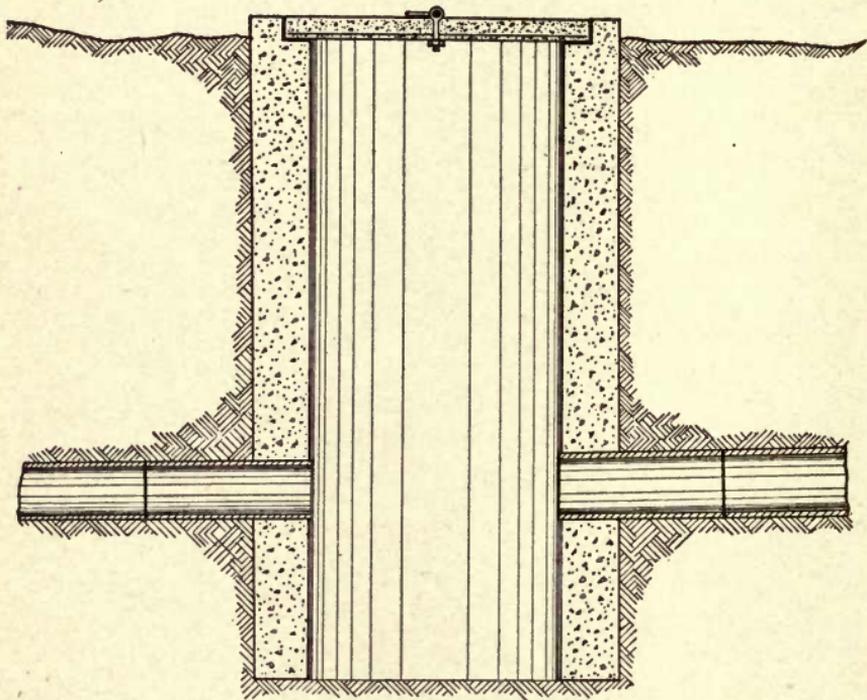


FIG. 35. — Silt-basin built of concrete.

The basin should be at least 12 inches in diameter or 18 to 24 inches for large tile. As the water enters the silt-basin from the tile, its velocity is suddenly decreased and its capacity to carry silt is thus reduced. Therefore most of the silt settles to the bottom of the silt basin as the water passes through and into the out-leading tile. When the silt has accumulated sufficiently in the bottom of the silt basin, it may be removed with a shovel or hoe.

122. The construction of a silt-basin. — A very common method of constructing a silt-basin is to dig an opening to a depth of at least 12 inches below the bottom of the outgoing tile, and from 20 to 30 inches in diameter, depending on the size of the tile leading into and from the basin. This opening is then walled or curbed with common brick to the top of the ground. (See Fig. 33.) Sometimes the opening is walled with brick to just above the top of the tile and then a piece of sewer pipe of sufficient diameter is placed on end upon the brick. Cement may be used in place of the brick. (See Fig. 34.) In regions where stone, and especially flat stone, is abundant, this material is much used in building walls of silt-basins.

In these days of cement, a very simple method of constructing a silt-basin is to dig an opening of proper size and then build in a wooden form, and fill the space between the form and the walls of the opening with a mixture of one part of cement to five or six of sandy gravel. (See Fig. 35.)

123. Finishing the silt-basin. — In most cases, it is desirable to carry the basin wall to a few inches above ground. Sometimes, however, where the field is cultivated, the top of the wall is stopped at 12 inches below the surface of the ground. A heavy covering is then placed on the top of the wall and the soil is filled in above it. In this case it is necessary to use some special means for locating the silt-basin.

Where the wall is brought to or above the surface of the ground, it should have placed upon it a substantial cover of wood, concrete, or iron. Iron gratings are used when it is desired to remove surface water by way of the tile drains (see paragraph 208).

CHAPTER V

LEVELING

LEVELING is a process by which the heights or elevations of definite points in a line or in an area above an arbitrarily adopted plane are determined. This is called the datum plane, and is usually so located as to lie lower than the lowest point whose elevation is sought. In the ordinary practice of leveling, for drainage purposes, this plane is so established that the point at which the leveling begins lies just 10 feet above it, — “10 feet above datum.”

It will be seen that if the datum plane is itself level, and if the height of each point is determined, in a line or in an area, above the datum plane, it is then an easy matter to determine the difference in elevation between any point and any other point, or to determine the fall between any two points.

124. The level. — The level shown in Fig. 36 consists of a telescope mounted on a spindle, which is in turn mounted on a tripod. The telescope carries a spirit level which is so carefully adjusted that when the bubble stands in the center the telescope stands level for that direction. When the tripod is set, the spindle can be adjusted so that the telescope swinging upon the spindle is always level.

As one looks through the telescope, one sees apparently near the far end two lines — one horizontal and the other perpendicular — crossing each other at the center of the

opening. These lines are called the cross-hairs. When the telescope stands level, *i.e.*, when the level attached to the telescope indicates level:

1. A line passing from the eye of the observer through the small opening through which he looks, and through

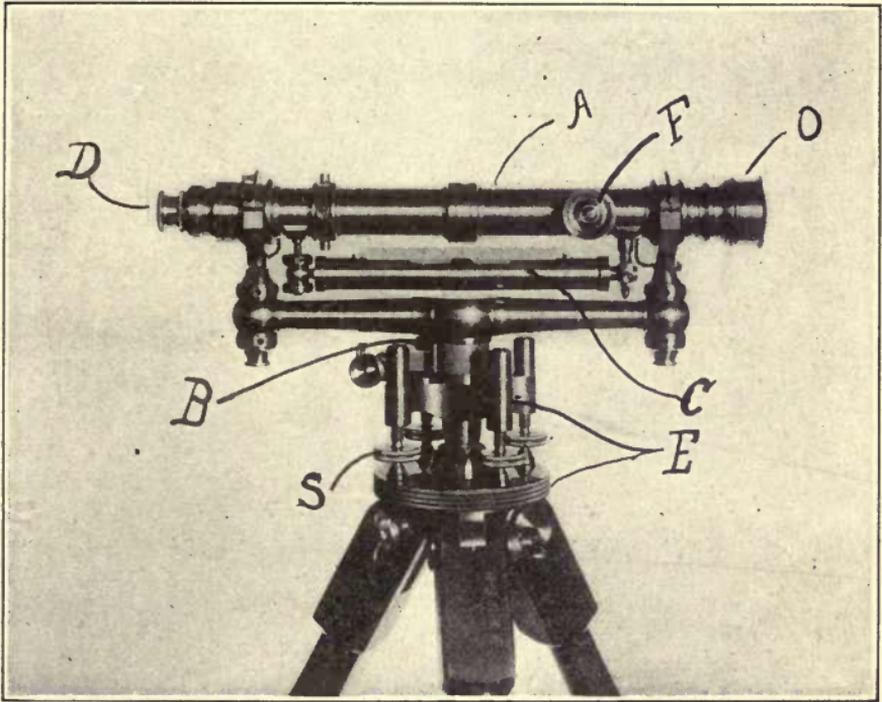


FIG. 36. — Level commonly used in drainage work. *A*, telescope; *B*, spindle; *C*, spirit level; *D*, eye-piece; *E*, leveling head; *F*, ratchet to adjust objective; *O*, objective; *S*, leveling screws.

the horizontal cross-hair, is also level and is parallel to the datum plane.

2. The distance of the horizontal cross-hair above the datum plane is called also the height of the instrument.

3. Every point that falls directly back of, or behind the horizontal cross-hair, as the observer looks through the

telescope, is the same height above the datum plane as is the instrument.

125. Cheaper levels. — The instrument shown in Fig. 36 is rather expensive for one who has only a limited amount of draining. A number of cheaper levels, also

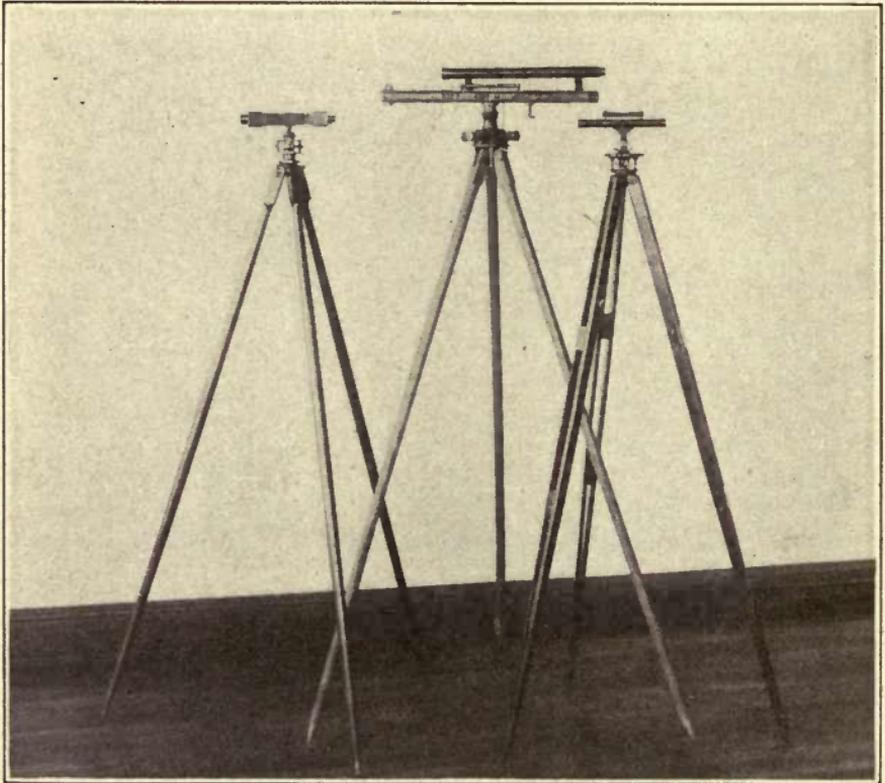


FIG. 37. — Cheaper forms of drainage or grade levels. Reading from left to right, Gurley, Jackson, Queen.

called drainage levels, can be secured. Some of these are also called grade levels. They are not as accurately made as the more expensive instrument, but they are sufficiently accurate for use where there is a fair fall, or grade, and for others than professional drainage engineers. Three such levels are shown in Fig. 37.

126. Leveling rods. — With the level there should be a leveling rod. Figure 38 shows two such rods; one (*a*) is known as the sliding rod. It is catalogued as an architect's rod. It consists of two parts, each in this case $5\frac{1}{2}$ feet long, fitted together and clamped in such a way that the parts may be extended to form a rod 10 feet long. A rod like *a* is shown extended in *b*. The other rod *c*, a simple affair, consists of a single piece $\frac{3}{4}$ inch by $1\frac{3}{4}$ inches by 8 feet long. These rods are graduated to feet, $\frac{1}{10}$ foot and $\frac{1}{100}$ foot. Rods are sometimes graduated to feet, inches, and fractions of an inch. Figure 39 shows a standard drainage engineer's leveling rod.

Sometimes the face of the rod is spaced or blocked in colors, the spaces or blocks representing fractions of a foot, so that the graduated face can be read at a distance and especially through the telescope of the level. The face of one rod in Fig. 38 shows this spacing.

127. Target. — Each of the rods shown in Figs. 38 and 39 is equipped with a target. The target is a circular plate divided into quarters by a horizontal and a perpendicular line, and the quarters painted red and white as shown. The target is constructed to slide up and down

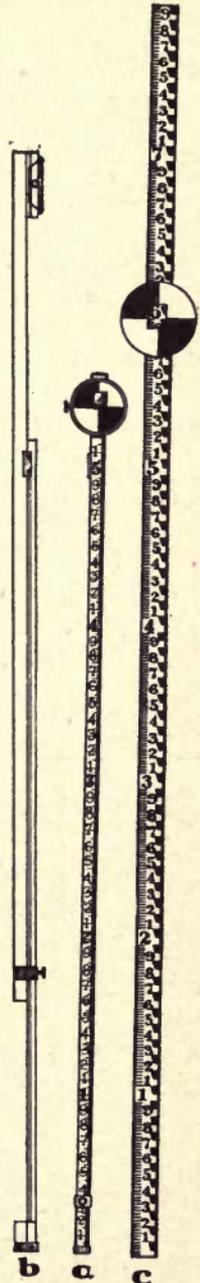


FIG. 38. — Leveling rods. *a* and *b*, two views of an architect's rod. *c*, view of a cheap rod accompanying the Jackson level.



FIG. 39.— Drainage engineer's leveling rod.

in grooves on the rod, or upon guides, and is fitted with a clamping screw. The target is open in the center to expose a portion of the face of the rod. (See Fig. 40.)

128. Using the level.

— In using the level observe that :

1. There is always a starting point whose elevation above datum is known, or arbitrarily established or, to put it more correctly, below which a datum plane is arbitrarily established. Ordinarily in simple drainage work, this arbitrary height or elevation is 10 feet.

2. There are one or more other points whose elevations are not known, but which it is desired to determine. The procedure is about as follows :

129. Setting up the level. — The level is set up :

1. At a convenient place within range of a

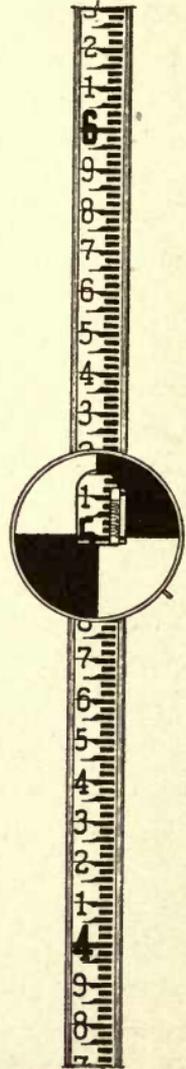


FIG. 40.— Target.

point whose elevation is known, or has been established ; it is set, with the legs of the tripod spread in such a way that when they are firmly set in the soil, the lower plate of the leveling head *E*, Fig. 36, is approximately level.

2. The upper plate and spindle are then adjusted by the use of the thumb-screws of the leveling head, so that the spirit level indicates level in whatever direction the telescope is turned. In practice, the telescope is turned so that it stands in line with two opposite thumb-screws, and adjustment is made to bring the telescope to level. It is then turned so that it stands in line with the other pair of thumb-screws and adjusted as before. The telescope is now turned back to its first position for re-adjustment, then reversed, then turned to its second position and reversed, and in each case the thumb-screws are used, if necessary, to perfect the adjustment to bring the telescope to level. When thus adjusted, the telescope should stand level in all positions.

130. Cautions. — The following cautions should be observed in setting up the level :

1. Tighten the thumb-screws only sufficiently to hold the telescope firmly. More than this is likely to do injury to screws and plates.

2. Remember that once the level is carefully adjusted, continual care must be exercised to keep it in adjustment. It should not be struck ; one should not stand too near the feet of the tripods ; the bubble of the spirit level should be frequently observed.

131. Determining the height of the level. — The height of the instrument is determined in the following manner :

1. A leveling rod is held by an assistant, or rodman, on a point whose elevation is known, or has been es-

tablished. The rod should be held perpendicular with the face toward the level.

2. The person in charge of the adjusted level turns the telescope toward the rod, places the eye at the eye piece, and moves the objective out or in until the figures upon the face of the leveling rod are clearly seen or, if the rod is too far away for that, till the view of the target is clear cut. The eye piece may need adjusting to bring out clearly the cross-hair. He should look now to see that the spirit level indicates level and, if necessary, adjust.

132. Direct reading. — If the figures on the leveling rod appear sufficiently clear to the one in charge of the level, as he looks through the telescope, he should read and record the height on the rod at which the horizontal cross-hair crosses the face of the rod.

133. Target reading. — If the figures on the leveling rod do not appear sufficiently clear to be read by the person in charge of the level, then the rodman must raise or lower the target as directed by signs from the person in charge of the level, until the horizontal bisecting line of the target lies exactly behind the horizontal cross-hair of the telescope as seen through the telescope. The rodman should now carefully tighten the set screw of the target and then read to the level-man the height at which the horizontal bisecting line of the target crosses the face of the rod. This height the level man should carefully record. The rodman may record the reading.

134. Back-sight reading and its use. — This reading is called the back-sight, and is the name always given to the reading taken at the point whose elevation is known, or assumed, and is always taken to determine the height of the instrument. Let us suppose the reading just taken to be 4.95 feet. This means that the instrument is

4.95 feet above the point at which the rod was held. Let us suppose also the height of the point at which the rod is held to be 11.35 feet above datum. If, now, we add 4.95 feet to 11.35 feet, we have 16.30 feet as the height of the instrument above datum.

135. Elevation of other points. — The height or elevation of other points within range of the level are determined in the following way :

1. The rodman carries the rod and holds it, face toward the level, upon one of the points whose height is sought.

2. The telescope is turned toward the rod in its new position and focused to bring out, most clearly, the figures on the face of the rod. The reading is taken as in (133) above and recorded.

136. Fore-sight reading and its use. — This reading is called a fore-sight, which is the name given to any reading taken at the point whose elevation is to be determined. Let us suppose that this fore-sight reading is 4.22 feet. It means that the point at which the rod is held, and whose elevation is sought, is 4.22 feet lower than the instrument, — 4.22 feet nearer the datum plane than is the instrument. If, then, we subtract 4.22 feet (the fore-sight reading) from 16.30 feet (the height of the instrument), we obtain 12.08 feet as the elevation of the new point.

In like manner the rod should be placed at other points within the range of the instrument, and fore-sight readings taken. In each case, subtracting its fore-sight reading from the height of the instrument gives the elevation of the point at which the fore-sight reading was taken. Let us suppose three other fore-sight readings are taken at three other points, respectively, and that these three readings are 3.75 feet, 3.06 feet and 3.11 feet.

137. Cautions.—In taking a reading, the following cautions should be observed:

1. Always before recording a reading, observe the bubble in the spirit level to be sure that the telescope is level.

2. If at any time the level should be disturbed, it should be properly set and its height redetermined before taking other fore-sight readings. In establishing the new height of instrument, a reading may be taken to any point whose elevation is known.

138. Records and computations.—Every reading should be carefully recorded in its proper place in a table provided for the purpose. If it is desired merely to find the elevation of several points, the form of table given below will serve the purpose. (See Table VIII.) Usually the figures are introduced into the table as they are obtained in the work of leveling, and the computations are made later.

TABLE VIII

POINT OR STAKE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVATION
1	4.95	—	—	11.35
2	—	—	4.22	—
3	—	—	3.75	—
4	—	—	3.06	—
5	—	—	3.11	—

139. Directions and explanations.—The following points should be observed:

1. That the elevation of point 1 had already been established or assumed. It should be recorded after point 1, under elevation.

2. The back-sight was taken at point 1. It is always taken at a point whose elevation has been established.

3. Each fore-sight reading is recorded after the point at which it was taken.

4. In making computations for determining the elevation of the other four points, the back-sight reading 4.95 feet is added to the elevation of point 1, which in this case is 11.35 feet. This gives 16.3 feet as the height of the instrument above datum and this is introduced after the back-sight reading under height of instrument, as appears in Table IX.

5. The elevation of each point is found by subtracting its fore-sight reading from the height of the instrument, and when all the elevations are thus found and introduced the completed table appears as is shown in Table IX.

TABLE IX

TABLE VIII COMPLETED

POINT OR STAKE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVATION
1	4.95	16.30	—	11.35
2	—	—	4.22	12.08
3	—	—	3.75	12.55
4	—	—	3.06	13.24
5	—	—	3.11	13.19

140. **Moving and resetting the instrument.** — If there are other points too high, or too low, or too far away to fall within the range of the level, it must be moved and set at a new place, so that one or more of the other points shall fall within its range, and such that one of the points whose elevations have already been found shall also lie

within range of the level. The height of the instrument at this new position is now determined, the back-sight reading being taken at a point within range, and whose elevation is already found, or whose elevation can be found from data already obtained. If the new points whose elevations are sought are in the same line of stakes as those already found, it is desirable to take the back-sight reading at the stake whose elevation was last found. The work from this point proceeds as above described.

141. Using cheaper kinds of levels. — The cheaper kinds of drainage levels are of necessity more crudely made and cannot, therefore, be so delicately adjusted as the better made and more expensive instruments.

In leveling with these cheaper instruments, usually only one fore-sight reading is taken with each setting up. One back-sight reading must also be taken, because this is necessary to determine the height of the instrument. In using the cheaper level, the precaution should always be observed of setting the instrument nearly equidistant from the point whose elevation is known and the point whose elevation is to be determined. In practice, in leveling for drains where the fall is large, it is possible, with care, to take two, three, or even four fore-sight readings with each setting up of the instrument. But here, as above, the level should be set very nearly midway between the point whose elevation is known and the farthest point whose elevation is to be determined with this setting of the instrument.

If but one fore-sight reading were taken with each setting up of the instrument in determining the elevations of the points recorded in the tables above, the readings would appear as seen in the following table :

TABLE X

POINT OR STAKE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVATION
1	4.95	—	—	11.35
2	4.87	16.30	4.22	12.08
3	5.07	16.95	4.40	12.55
4	4.66	17.62	4.38	13.24
5	—	17.90	4.71	13.19

142. Simple devices sometimes used in leveling. — Where tile of good size is to be laid with a fair fall, rather crude devices are sometimes used for leveling, with satis-

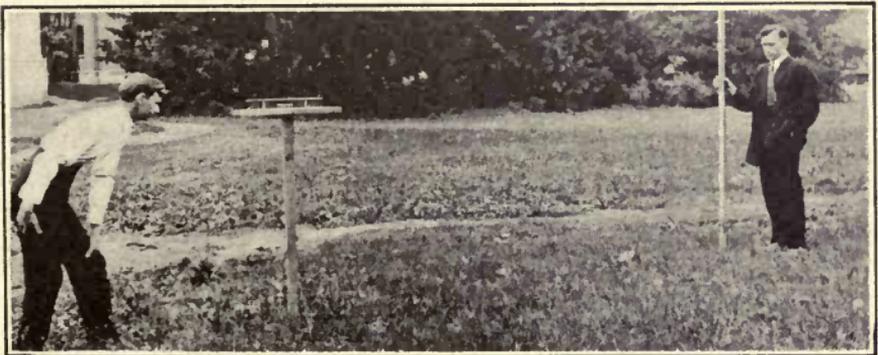


FIG. 41. — Illustrating how a carpenter's level may be mounted on a stand and used for leveling.

factory results. There are frequently found advertised in our agricultural journals, cheaper leveling devices, ranging from \$5 to \$10 apiece.

143. The carpenter's level. — A device sometimes used is illustrated in Fig. 41. It consists of a one-legged stand with the lower end of the leg sharpened so that it can be pushed into the ground sufficiently to hold the stand firmly upright, and so that the top of the stand shall be approximately level. Upon the top a carpenter's level is placed

and, by the use of wide thin wedges, adjusted to level. Over the top of the level thus adjusted the operator may sight. Figure 41 shows the level in use.

144. The water level. — Figure 42 shows what is sometimes spoken of as the water level. It consists, in this case, of two glass tubes firmly clamped to a bar which in turn is firmly fastened to a sharpened leg. The lower



FIG. 42. — Illustrating the water level in use.

ends of the tubes are connected by a piece of rubber tubing. A colored fluid is introduced through one of the tubes until it stands within an inch of the tops of the glass tubes, care being taken to have the bar nearly horizontal. In accordance with a law of fluids, the tops of the columns of colored liquid in the glass tubes stand at the same level. A line passing over the tops of the columns of fluid, therefore, when the fluid has come to rest, is level. Sometimes horizontal sliding sights are set on the tubes. When the fluid comes to rest, each sight is set even with the top of the column of fluid in its tube. The sighting is then done over these sights. (See also Fig. 43.)

With these home-made devices there must also be used a leveling rod, which is also usually home-made, the making of which will vary with the notions of the maker.

145. The hose level. — In Chapter IX there is described a device for leveling which is cheap to construct, simple to operate, and accurate in results obtained. It consists of a piece of inch or $\frac{3}{4}$ -inch or even $\frac{1}{2}$ -inch garden hose about 60 feet long, into the ends of which have been

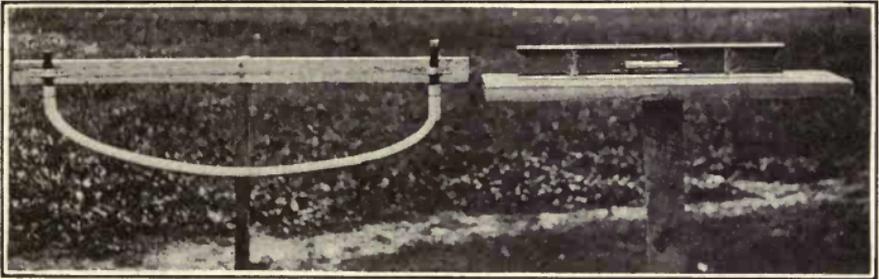


FIG. 43. — Closer view of water level and carpenter's level.

clamped 12-inch pieces of water gauge tubing. With the ends brought near together and held in an upright position, water is introduced till the hose is filled and the water stands in the tubes half their lengths. The two columns of water stand at the same height as shown in Fig. 67 regardless of the position of the hose.

CHAPTER VI

LAYING OUT A DRAIN OR SYSTEM

WHEN the tile draining ranges from a single line of tile to a system draining a moderate area, with reasonable facilities for an outlet, and with a fair fall, it is entirely practicable for the farmer to do the work himself. On the other hand, when the area to be drained is large, and especially when the fall must of necessity be very slight, it is usually better to place the work in the hands of a practical drainage engineer. In any case the work should be taken up much as outlined below.

146. Establishing the point of outlet. — The first thing to be done is to determine the point at which the drain, or system, shall discharge its water. We have already indicated in paragraph 112 how important a matter this is. Upon it depends not only the regular and proper disposal of the water discharged from the system, but the plan and efficiency of the system itself, and the economy that may be exercised in its construction. A tile drain or a tile system should be planned not for a few years, but for generations of service.

147. Laying out a drain. — If the drain is to be single or simple, one should begin at the point determined upon for the outlet, and establish the line of the drain by driving stakes at intervals of 50 feet.¹ Two kinds of stakes should be provided.

148. Grade stakes. — These stakes should be about 1 inch by $1\frac{1}{2}$ inches, 10 inches long, and pointed. In

¹ With many engineers 100 feet is preferred.

clay soils 8 inches is long enough for the grade stakes, while in looser soils, such as mucks, the length should be 12 to 15 inches. The grade stakes should be driven in straight lines, 2 inches back from the intended edge of the ditch. If the ditch is not to be straight throughout its entire length, the breaks should be made if possible at a point or points established by the grade stakes. They should all be driven on the same side of the ditch; at least this should be true for any one section of the drain. They should be driven so that the tops stand about $\frac{1}{2}$ inch above the ground in each case, and to secure uniformity in height above the ground, it is a good plan to carry a small piece of $\frac{1}{2}$ -inch board, 6 inches by 12 inches, and to lay this board on the ground next to the stake and drive the stake until its top shall stand just even with the upper surface of the board. In this way the effects of the little inequalities in the soil are overcome. These stakes should be driven so that their greatest width stands parallel with the edge of the drain.

149. Finders. — About 6 inches back from each grade stake should be driven another stake, commonly called a finder. This should be 18 inches to 2 feet long, $\frac{7}{8}$ inch thick, and 2 to 3 inches wide, and should be driven from 4 to 6 inches into the ground. The finder assists in the subsequent locating of the grade stakes, and sometimes has recorded upon it data concerning the ditch. These data are usually placed upon the finder for the benefit of the man who digs the ditch, and may include such items as the depth of the ditch at this point, the distance of the stake from the terminal of the ditch, the height of the grade bar, the boning line, and the like.

150. Laying out a main. — The procedure in laying out a main will not differ from that in laying out a single

or simple ditch, excepting that the grade stakes may be driven at intervals other than 50 feet. In laying out the main, the grade stake usually establishes also the point at which the laterals connect with the main and, therefore, the starting point of the laterals. If the laterals are to be located at intervals of 100 feet, and the laterals on opposite sides of the main are to alternate and to lie at right angles to the main, as shown in Fig. 26, then 50 feet is the proper interval to be adopted between grade stakes. If the laterals on one side of the main are to be located at intervals of 60 feet, and are to lie at right angles to the main, then the grade stakes should be set at intervals of 30 feet. In other words, the interval between any two grade stakes is one-half the interval between any two laterals on one side of the main. This is, of course, under the assumption that the intervals between laterals are uniform.

151. Fifty-foot intervals. — The 50-foot interval between grade stakes is chiefly desirable because in thinking of, and discussing, the fall of drains, the fall in inches is almost invariably compared with 100 feet of length of drain. When a drain is said to have a fall of three inches, a fall of three inches in 100 feet of drain is meant. Fifty feet is just one-half of 100 feet, and if the rate of fall is 3 inches for 100 feet, then the fall in 50 feet is $1\frac{1}{2}$ inches. If the interval between stakes is any other than 50 feet, some other factor than one-half must be used in determining the fall between stakes. The next easiest distance to use for intervals between stakes is 25 feet, which is one-quarter of 100 feet, and the next is 33 feet 4 inches, which is one-third of 100 feet.

152. The relation of angle of approach to the main to the actual distance between laterals. — In some

respects it is desirable that the laterals lie at angles less than 90° to the main: (1) with an angle less than 90°, it is not necessary to introduce a curve or angle at the outlet end of the lateral; (2) in very many cases the outlet of the area to be drained is other than square, and can be more economically served by the lateral if it lies at an angle less than 90 degrees to the main.

When two laterals, entering the main at an interval of 100 feet, lie at an angle of 30 degrees to the main, they are just 50 feet apart. If two laterals, entering the main 100 feet apart, lie at an angle of 60 degrees to the main, their distance apart is nearly 86 feet, 7 inches. If two laterals, entering a main 100 feet apart, lie at an angle of 45 degrees, the distance between them is nearly 70 feet, 8 inches. (See Fig. 44, also Table XI.)

TABLE XI

RELATION OF ANGLE OF APPROACH TO MAIN TO DISTANCE BETWEEN LATERALS, WHEN LATERALS ENTER MAIN 100 FT. APART

ANGLE	DISTANCE BETWEEN DRAINS		RELATION
	Feet	Feet and Inches	
30°	50	50 0	.50
35	57.358	57 4½	.5736
40	64.279	64 3½	.6428
45	70.711	70 8½	.7070
50	76.604	76 7	.7660
55	81.915	81 11	.8192
60	86.603	86 7	.8660
65	90.631	90 7½	.9063
70	93.969	93 11½	.9367
75	96.593	96 7	.9659
80	98.481	98 6	.9848
85	99.619	99 7½	.9962

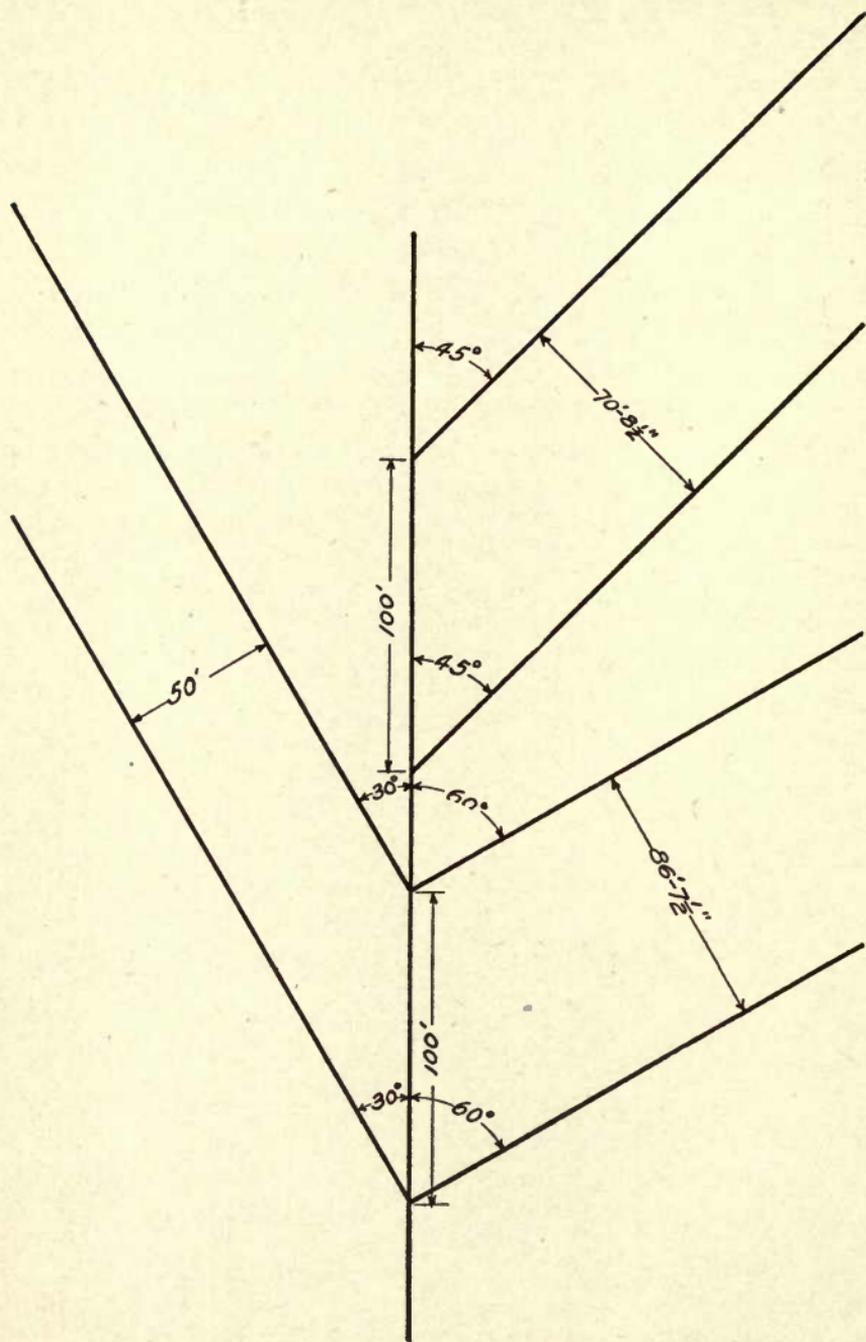


FIG. 44. — Relation of the angle of approach to the distance between drains. See Table XI.

To determine the distance between laterals when they enter the main at a distance other than 100 feet, multiply distance by the relation factor of the angle at which they approach the main. Example: If laterals enter at distance 70 feet and approach at an angle of 50° (the factor for 50° is .766), $70 \times .766 = 53.620$ feet. The distance between laterals is 53.62 feet or 53 feet $7\frac{1}{2}$ inches nearly.

153. Laterals. — The laying out of a lateral is in no way different from that of a simple drain, as described in paragraph 146, excepting that the laterals discharge at their lower terminal into the main or sub-main, and not at an outlet. It is most convenient to drive the grade stakes at intervals of 50 feet, for reasons given in paragraph 147, and for the further reason that a greater distance than 50 feet increases the difficulty in using the boning line.

154. The angle of approach for laterals. — It is common, in systems like that illustrated in Fig. 25, to locate the laterals so that their upper angle to the main shall be less than 90 degrees. If, however, it should be deemed advisable to run the lateral at right angles to the main, as shown in Fig. 26, then they should be turned slightly as they approach the main so as to enter at an angle of less than 90 degrees, the reason being that if the water from the lateral is discharged into the main at an angle of 90 degrees, it is likely to interfere with the movements of the water and also with the ready movement of the silt which may be carried by the waters of the main. Another factor, however, that must enter into the angle of approach is the position and shape of the area requiring drainage. (See Figs. 28 and 29.) The angle of approach must be determined by the needs of the land and economy

in labor. The angle of discharge should be governed by the suggestions above.

155. The location of the upper end of mains and laterals. — It is not necessary to carry the end of either main or lateral to the very edge of the area to be drained. The water in the soil will move toward the end as readily as it will toward any other point in the drain. The line of equal influence of the drain at this point is the arc of a circle whose center is the end of the drain.

156. Measurements. — Due care should be exercised in laying out each simple drain, main and lateral. The distance between stakes should be carefully measured, and the distance of each stake from the lower end of the drain carefully recorded. This information will be needed (1) in determining the grades, and (2) in estimating the size and the amount of tile needed.

157. Estimate of tile and order for it. — If a preliminary survey and estimate of the size and amount of tile needed has not already been made, this should be done now, and the tile ordered. Paragraph 116 should be studied to assist in making these estimates.

Many of the manufacturers of glazed tile manufacture also angles for connecting laterals to mains and sub-mains. When glazed tile is used, it is well to purchase these angles for connections, and the number and sizes needed should be included in the order.

158. Hauling and distributing tile. — While not absolutely necessary, it is desirable that the tile be hauled upon the ground and distributed near the lines in which it is to be used, before the leveling begins. The driving of teams and the handling of the tile is likely to result in disturbing the grade stakes, and these should not be disturbed from the time the leveling is completed till

the tile is laid in the bottom of the ditch. It is not so convenient, and it is more expensive, to distribute the tile after the digging of the ditch has begun.

159. Leveling for the drain. — If there is a system of drains to install, the work of leveling begins with the main. If there is only a single drain, the work of leveling will proceed in much the same manner. The object of the leveling is to determine the elevation above datum of the surface of the field at each stake along the proposed drain, or at each stake in the proposed system, as the case may be. The reasons for this will appear later. The manner of doing the work of leveling will be the same as was described in paragraphs 128–140.

160. Steps in the procedure. — The work of leveling will begin at the stake driven at, or nearest to, the proposed outlet. This stake is numbered 1.

a. If the level to be used is a high class instrument, and the drain is not over 60 rods long, it may be set up at about the middle of the length of the drain. The elevation of stake 1 will be assumed to be 10 feet above datum and recorded as such in the proper column, after stake 1 in the notes.

The first reading will be a back-sight reading taken at stake 1 and will be recorded in the proper column, after stake 1 in the notes. This back-sight reading, added to the recorded height of stake 1, gives the height of the instrument. A fore-sight reading should now be taken at every other stake within the range of the level along the proposed drain. Each fore-sight reading should be recorded in the notes after the number of the stake at which it is taken. If all the stakes of the drain do not fall within range of the instrument, one or more re-settings will be necessary.

Each of these fore-sight readings, subtracted from the height of the instrument, gives the elevation of the stake at which the reading was taken.

Observe the cautions suggested in paragraphs 130 and 137.

b. If the level to be used is not a high class instrument, it should be set a little to one side of the proposed drain, and about equidistant from stakes 1 and 2. As above, the elevation of stake 1 is assumed to be 10 feet above datum, and is recorded in the proper column after stake 1 in the notes.

A back-sight reading should be taken with the rod on stake 1, and recorded in the proper column after stake 1 in notes. This reading, added to the height of stake 1, will give height of instrument.

A fore-sight reading should be taken with the rod on stake 2, and recorded in the proper column, after stake 2 in notes. This reading, subtracted from the height of instrument, will give elevation of stake 2.

In like manner the instrument should be set in a similar position between stakes 2 and 3, a back-sight reading should be taken at stake 2, and a fore-sight reading at stake 3. The back-sight reading, added to the elevation of stake 2, will give the height of instrument in the new position, and subtracting the new fore-sight reading from this new height of instrument will give the elevation of stake 3.

Proceed in this way, taking a back-sight and a fore-sight reading between each two stakes, till the fore-sight reading is taken on the last stake.

As stated in paragraph 141, where there is a fair fall, these cheaper levels may be set up to take 3, and even 5 or 7 fore-sight readings for each back-sight reading. In

any case, the instrument should be set so that it shall stand approximately mid-way between the stake at which the back-sight reading is taken, and that at which the last fore-sight reading is to be taken.

NOTE: Observe carefully the cautions suggested in paragraph 137.

161. **Keeping notes.** — A more extensive form must now be employed for keeping records of readings, and the like, than was shown in paragraph 138. A table like the following is suggested :

TABLE XII

NO. OF STAKE	DIS-TANCE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVA-TION	FALL	ELEVA-TION OF BOTTOM OF DITCH	DEPTH OF DITCH	HEIGHT OF LINE
1	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—

In column 1 are recorded the stake numbers in order. In column 2 is recorded the distance of each stake from stake 1. With these distances the distance between any two stakes may be found.

As the work of leveling progresses, the back-sight readings should be properly recorded in column 3, and the fore-sight readings in column 5.

Usually, though not necessarily, all readings are taken before computations to determine the elevations of the several stakes are begun. This, of course, includes the determination of the height of instrument after each back-sight reading.

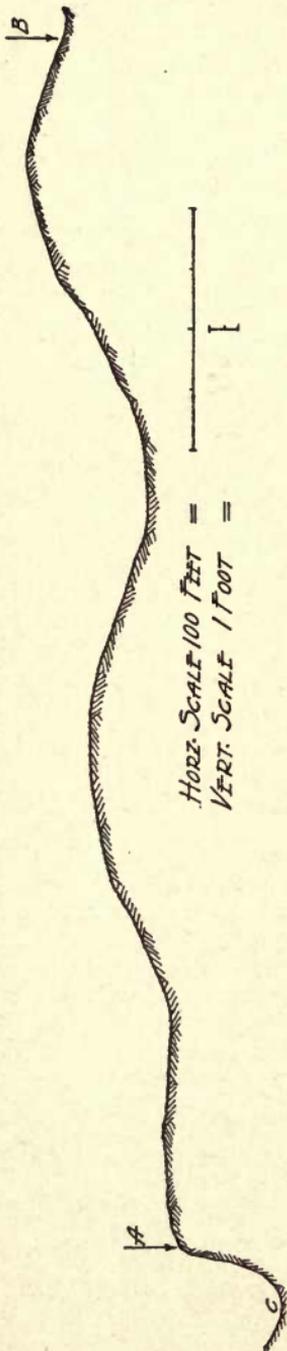


FIG. 45. — Profile of a portion of field through which a tile drain is to be laid.

162. Some convenient aids. —

To make the succeeding steps more clear, and to illustrate some simple means to assist the operator in establishing grades, and the like, let us take up a piece of actual work, with diagram and the data used in carrying it to completion.

In Fig. 45, *A-B* represents the profile of the surface of a portion of a field in which it was necessary to place a tile drain. The distance *A* to *B* is 500 feet. In the original drawing, 2 inches horizontally equaled 100 feet, while $\frac{1}{4}$ inch vertically equaled one foot. Using different scales for the two dimensions destroys the proportions and requires some use of the imagination. *A-C* represents a fall which provides a good outlet.

Figure 46 represents the same surface with the grade stakes driven 50 feet apart, according to directions in paragraph 150, and numbered (1-11). Only one finder is shown in place, and that at grade stake 7.

163. Leveling with cheaper levels. — Figure 47 shows a cheaper form of level described in paragraph 125, in three positions, that is, first, between stakes 1 and 2, second, between stakes 2 and 3, and third, between stakes 3 and 4. It shows, also, the leveling rod in positions successively at which it would be held to obtain the three back-sight and the three fore-sight readings spoken of in paragraphs 134 and 136. There are shown, also, the directions in which the three back-sight and the three fore-sight readings were taken, with their values. These readings will be found in columns 3 and 5 in the table on the following page.

There will be found in columns 3 and 5, also, the readings taken for determining the elevations of the remaining stakes. In column 1 of the table are the numbers of the stakes 1 to 11, in column 2 is shown the distance of each stake from stake 1. In this case the stakes are located 50 feet apart, so that stake 2 is 50 feet from stake 1, and stake 3 is 100 feet from stake 1, and so on up to stake 11, which is 500 feet from stake 1.



FIG. 46. — Same as Fig. 45, with grade stakes and one finder in place.

With these data properly recorded in the table we are able later, by a series of computations, to obtain all the facts called for in the other columns of the table, and thus to obtain all the figures necessary to the proper construction of the drain.

TABLE XIII

SAME AS TABLE XII WITH BACK-SIGHT AND FORE-SIGHT READING AND DISTANCES INTRODUCED

NO. OF STAKE	DISTANCE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVATION	FALL	ELEVATION OF BOTTOM OF DITCH	DEPTH OF DITCH	HEIGHT OF LINE
1	0	4.75	—	—	—	—	—	—	—
2	50	5.00	—	4.25	—	—	—	—	—
3	100	5.50	—	5.17	—	—	—	—	—
4	150	4.83	—	3.58	—	—	—	—	—
5	200	5.06	—	4.13	—	—	—	—	—
6	250	4.65	—	5.51	—	—	—	—	—
7	300	4.92	—	5.91	—	—	—	—	—
8	350	5.75	—	4.31	—	—	—	—	—
9	400	4.80	—	3.30	—	—	—	—	—
10	450	3.78	—	3.70	—	—	—	—	—
11	500	—	—	4.98	—	—	—	—	—

164. Leveling with a high-grade level.— Figure 47 shows a high-grade instrument in position to take levels for the same drain. It is located near the center of the drain. The leveling rod is shown in position to take the single back-sight and also the first fore-sight reading, and the last fore-sight reading, with their values. The data obtained, including the remaining fore-sights, appear in their proper places in the following table, which is identical with Table XIII above:

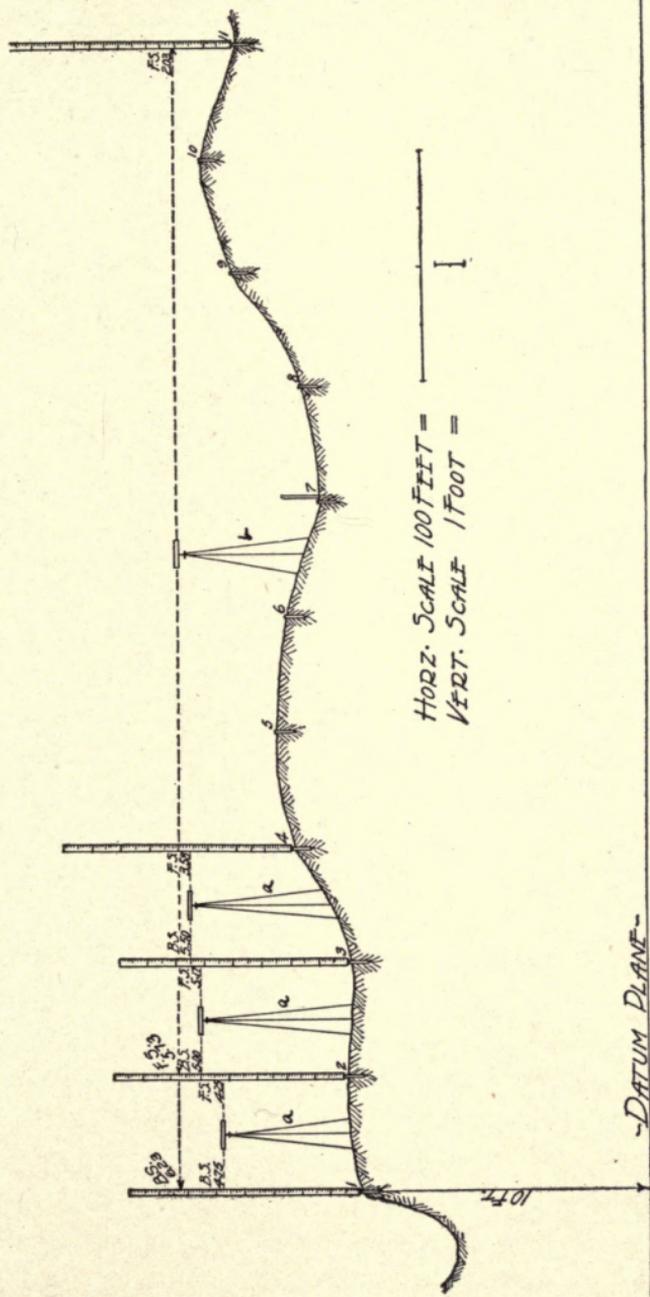


FIG. 47. — Same as Fig. 46, showing cheaper form of grade level (a) in 3 positions with back-sight and fore-sight readings indicated in each position. Showing also a standard level (b) in position, with one back-sight and two fore-sight readings. (Datum plane indicated.)

TABLE XIV

NO. OF STAKE	DISTANCE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVATION	FALL	ELEVATION OF BOTTOM OF DITCH	DEPTH OF DITCH	HEIGHT OF LINE
1	0	6.23	16.23	—	10	—	—	—	—
2	50	—	—	5.73	—	—	—	—	—
3	100	—	—	5.90	—	—	—	—	—
4	150	—	—	3.98	—	—	—	—	—
5	200	—	—	3.28	—	—	—	—	—
6	250	—	—	3.73	—	—	—	—	—
7	300	—	—	4.99	—	—	—	—	—
8	350	—	—	4.38	—	—	—	—	—
9	400	—	—	1.93	—	—	—	—	—
10	450	—	—	0.83	—	—	—	—	—
11	500	—	—	2.03	—	—	—	—	—

It will be observed, however, that there is but one back-sight reading in this case to be introduced into the back-sight column, and that after the number of the stake at which the back-sight reading was taken.

165. Making the computations. — With the fore-sight and back-sight readings recorded in the table, the first step is to determine the elevations of the several stakes. Since the cheaper instrument is the one most likely to be used except by professional engineers, let us use the data in Table XIII for the determination of the elevations of the stakes. If the reader is sure that he understands the processes of determining the elevations, he may disregard what follows in paragraph 166. If he is not sure, it is suggested that he refer to Table XIII, in which there is entered all the data developed to this point in the work, and that, following directions below, he determine the proper values and

enter them in columns 4 and 6 of the table; or he may rule a table for the purpose.

166. Computations in detail. — Observe that the back-sight reading taken at stake 1 is introduced on the line belonging to stake 1, and that in like manner each back-sight reading is introduced on the line of the stake at which it is taken. Observe, also, that each fore-sight reading is introduced upon the line of the stake at which it was taken.

1. We assume the elevation of stake 1 to be 10 feet above datum. This we record on line 1 in column 6. Figure 47 shows the location of the datum plane.

2. Add the first back-sight reading, 4.75 feet, to the elevation of stake 1. This gives 14.75 feet as the height of the instrument above datum. The height should be recorded on line 2 in column 4. Subtract the fore-sight reading, 4.25 feet, from this height of instrument. This gives 10.50 feet as the elevation of stake 2. This elevation we record on line 2 in column 6.

3. Add the back-sight reading, 5 feet, to the elevation of stake 2. This gives the height of the instrument, 15.50 feet, in its second position. Record properly. Subtract from 15.50 feet the fore-sight reading, 5.17, and we have 10.33 feet as the elevation of stake 3. This elevation we record on line 3 in column 6.

Observe (1) That with each setting of the instrument one back-sight and one fore-sight reading were taken. (2) That adding the back-sight reading to the elevation of the stake at which it was taken, and subtracting from this sum the fore-sight reading, gives the elevation of the stake at which the fore-sight reading was taken.

Proceed in this manner until the elevations of all the stakes have been found, in each case recording the

height of instrument and elevation of stake in the proper places.

At this point compare the results with those recorded in Table XV below. If they do not agree in all cases go over the work to discover and correct the difficulty.

TABLE XV

SAME AS TABLE XIII — ELEVATIONS INTRODUCED

NO. OF STAKE	DIS-TANCE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVA-TION	FALL	ELE-VATION OF BOT-TOM OF DITCH	DEPTH OF DITCH	HEIGHT OF GRADE BAR
1	0	4.75	—	—	10 ft.	—	—	—	—
2	50	5.00	14.75	4.25	10.50	—	—	—	—
3	100	5.50	15.50	5.17	10.33	—	—	—	—
4	150	4.83	15.83	3.58	12.25	—	—	—	—
5	200	5.06	17.08	4.13	12.95	—	—	—	—
6	250	4.65	18.01	5.51	12.50	—	—	—	—
7	300	4.92	17.15	5.91	11.24	—	—	—	—
8	350	5.75	16.16	4.31	11.85	—	—	—	—
9	400	4.80	17.60	3.30	14.30	—	—	—	—
10	450	3.78	19.10	3.70	15.40	—	—	—	—
11	500	—	19.18	4.98	14.20	—	—	—	—

167. A comparison of tables. — The data shown in Table XIV are those obtained for the same drain with a high-grade instrument. Observe that the single back-sight reading is introduced on the line of stake 1. The elevation of stake 1 is 10 feet, as in the other case. The back-sight reading is 6.23, which, added to the elevation of stake 1, gives the height of the instrument as 16.23. Subtracting any fore-sight reading from the height of the instrument gives the elevation of the stake at which

the fore-sight reading was taken. If the proper subtractions are made in Table XIV and the elevations properly introduced in the column for elevations, it will be observed that the elevations of the several stakes are identical with those for the same stakes as recorded in Table XV.

168. Preliminaries to establishing grade of ditch, cut, and the like. — We are now ready to establish the depth of the ditch at certain points, and to determine the fall. To help in these computations, a diagram or profile, similar to that shown in Fig. 48, should be used. This diagram is drawn upon ordinary profile paper. Figure 49 shows how the same work may be accomplished with a crude diagram drawn upon letter paper or rough note paper.

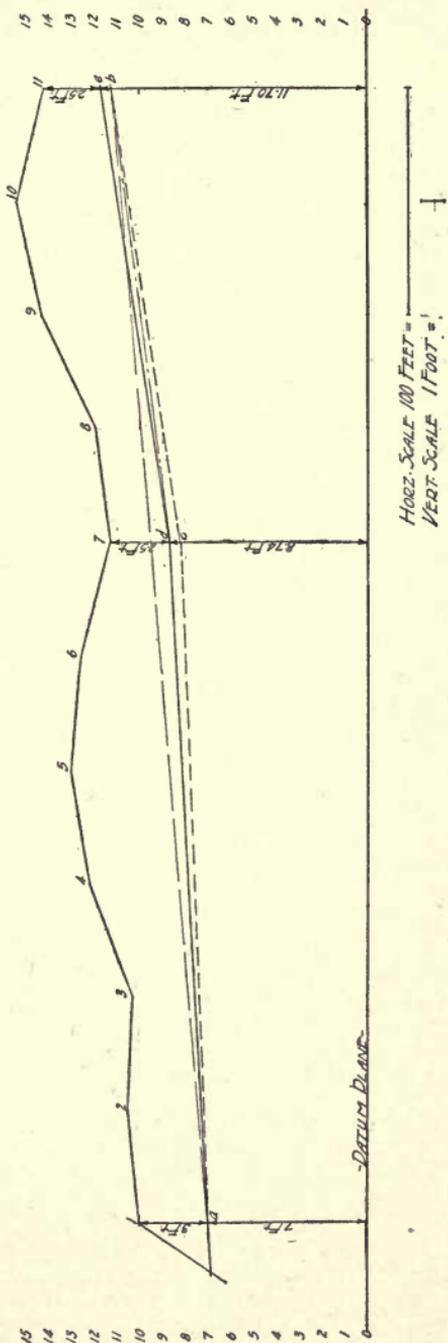


Fig. 48. — Diagram to determine fall and depth of ditch.

In this work we use the elevations as they now appear in Table XV. Two precautions are to be observed in this part of the work :

1. Not to have the ditch unnecessarily deep at any one or more points. Unnecessary depth means added expense in digging and filling.

2. To have the ditch sufficiently deep. Insufficient depth would endanger the tile from frost or even from plow points, and it would very likely fail to lower the ground water sufficiently for best results.

169. The grade or fall. — A good method of procedure is something as follows :

(a) Referring to Fig. 49, we find that conditions will permit a depth of 3 feet at stake 1, which is practically the outlet. Three feet is a satisfactory depth. Let us establish on our diagram, Fig. 49, point *a*, 3 feet below stake 1.

(b) For trial let us establish a point, *b*, 3 feet below the top of stake 11.

(c) If the fall in our ditch is to be constant, from point *b* to point *a*, a straight line connecting the two points will indicate the bottom of the ditch. We draw such a line.

It is very evident, as one looks at the diagram, after drawing the line *ab*, that this plan brings the drain very close to the surface at stakes 7 and 8. At either stake, if one applies the scale, the depth is found to be not over 18 inches, and, while drains are sometimes laid as shallow as this, a greater depth is desirable. It is further found that this drain would be only 27 inches deep at stake 3.

(d) Let us establish a point at *c*, 3 feet below the top of stake 7, and draw a dotted line from *a* to *c* and from *c* to *b*. We have now indicated the bottom of a drain that

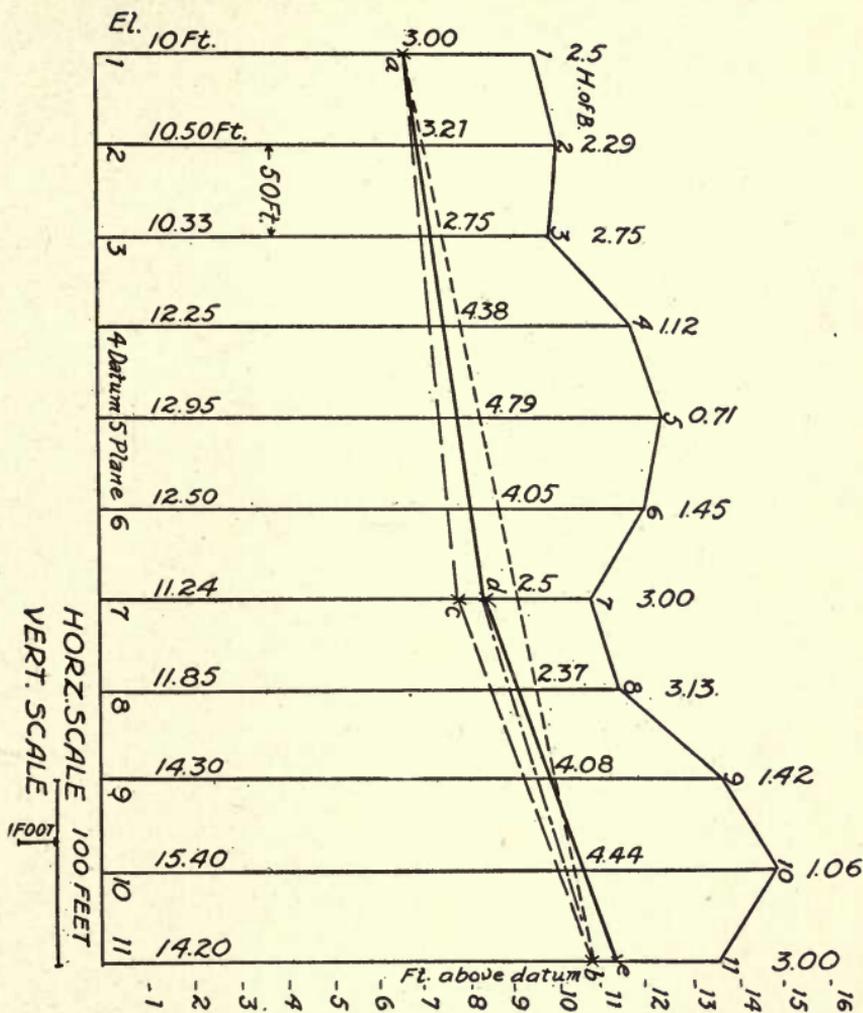


FIG. 49. — Diagram drawn on common note paper, but for the same purpose as that illustrated in Fig. 48. The space between lines represents one foot perpendicular. $\frac{1}{4}$ of an inch on the original represented 50 feet. The purpose of this figure is to show the value of such a diagram in forming a rather accurate estimate of the depth of the ditch at any point for any proposed initial depth and fall. The position of the lines on the note paper is indicated by the figures 1 to 16.

is little less than 3 feet deep at any point. But it is 5 feet deep at stake 5 and nearly 5 feet deep at stake 9. A 5-foot cut makes rather expensive digging. A compromise would be better in this case.

(e) Let us establish a new point, *d*, $2\frac{1}{2}$ feet below the top of stake 7 and a new point, *e*, $2\frac{1}{2}$ feet below top of stake 11, and draw a new line *d* to *e*, to represent the bottom of a drain from stake 7 to stake 11. This materially lessens the amount of digging at stakes 9 and 10.

(f) Let us adopt the line *ade* as the bottom of the drain.

Observe that the drain will be 3 feet deep at stake 1, $2\frac{1}{2}$ feet deep at stake 7, and $2\frac{1}{2}$ feet deep at stake 11. These depths we have established for convenience and economy in the work of digging. If this were a main drain it might be necessary, because of the laterals, to make the line (*acb*) the bottom of the drain. If, however, this drain were to be a lateral instead of a main, the line (*ade*) would be better for the bottom of a drain.

Observe, also, that the diagram we are using for this purpose brings out, more clearly, the relative depths of the drain at the several points.

(g) Introduce these depths in column 9 of the table — 3 feet on line 1, 2.5 feet on line 7, and 2.5 feet on line 11.

(h) If the depth is 3 feet at stake 1, the bottom of the ditch is 3 feet below the top of stake 1, or it is 3 feet lower than stake 1. If then we subtract the depth of the ditch, 3 feet, from the elevation of the stake, we have (10 feet — 3 feet =) 7 feet as the elevation of the bottom of the ditch, at stake 1, above datum. Subtracting the depth of the ditch, $2\frac{1}{2}$ feet, at stake 7, from the elevation at 7, gives 8.74 feet as the elevation of the bottom of the ditch at stake 7. Subtracting the depth of the ditch at stake

11, from the elevation of stake 11, gives 11.70 feet as the elevation of the bottom of the ditch at that point.

(i) Introduce these ditch-bottom elevations into column 8 of Table XV on their proper lines,—7 feet on line 1, 8.74 feet on line 7, and 11.70 feet on line 11.

(j) Before we can go further in finding values for columns 8 and 9, we must determine the fall or grade of the drain.

The elevation of bottom of ditch at stake 11 is 11.70 feet.

The elevation of bottom of ditch at stake 7 is 8.74 feet.

The fall of the drain from stake 11 to stake 7 is 2.96.

The distance from stake 11 to stake 7 is (500 feet — 300 feet =) 200 feet.

The fall to a 100 feet of this distance is (2.96 feet ÷ 2 =) 1.48.

Notice the way in which this fall is introduced in Table XVI.

The stakes along this drain are 50 feet apart, so that the fall from one stake to another is one-half of 1.48 feet, or .74 feet. In other words the bottom of the ditch at stake 10 will be .74 feet lower than at stake 11 and .74 feet lower at stake 9 than at stake 10 and so on.

11.70 feet = elevation of bottom of ditch at 11.

.74

10.96 feet = elevation of bottom of ditch at 10.

.74

10.22 feet = elevation of bottom of ditch at 9.

.74

9.48 feet = elevation of bottom of ditch at 8.

.74

8.74 feet = elevation of bottom of ditch at 7.

Observe, that our last remainder, 8.74 feet, is the elevation of bottom of ditch already indicated in column 8, which indicates that the subtractions to this point are correct.

Introduce the elevations of ditch bottoms at stakes 8, 9, and 10 in column 8 of Table XV.

The elevation of bottom of ditch at stake 7 is 8.74 feet.

The elevation of bottom of ditch at stake 1 is 7.00 feet.

The fall from stake 7 to stake 1 is 1.74 feet.

Find the fall to a hundred feet from stake 7 to stake 1 and record in column 7 in Table XV and compare your result with that in Table XVI.

Find the fall also for 50 feet and determine the elevations of bottom of ditch at stakes 6, 5, 4, 3, and 2. Introduce these elevations into the proper places in column 8. Then compare your results in column 8 with those in column 8 of Table XVI.

TABLE XVI

NO. OF STAKE	DIS-TANCE	BACK-SIGHT	HEIGHT OF INSTRUMENT	FORE-SIGHT	ELEVA-TION	FALL	ELEVA-TION OF BOT-TOM OF DITCH	DEPTH OF DITCH	HEIGHT OF GRADE BAR
1	0	4.75	—	—	10 ft.		7	3	2.5
2	50	5.00	14.75	4.25	10.50	.58 ft. in 100 ft.	7.29	3.21	2.29
3	100	5.50	15.50	5.17	10.33		7.58	2.75	2.75
4	150	4.83	15.83	3.58	12.25		7.87	4.38	1.12
5	200	5.06	17.08	4.13	12.95		8.16	4.79	.71
6	250	4.65	18.01	5.51	12.50		8.45	4.05	1.45
7	300	4.92	17.15	5.91	11.24		8.74	2.5	3.00
8	350	5.75	16.16	4.31	11.85	1.48 ft. in 100 ft.	9.48	2.37	3.13
9	400	4.80	17.60	3.30	14.30		10.22	4.08	1.42
10	450	3.78	19.10	3.70	15.40		10.96	4.44	1.06
11	500	—	19.18	4.98	14.20		11.70	2.5	3.00

170. The depth of cut. — We are now ready to determine the depth of the ditch at the stakes where the depths have not yet been determined. In column 6 of the table we have the elevations of all the stakes, while in column 8 we have the elevations of the bottom of the ditch at all the stakes. If now the elevation of the bottom of the ditch at any point is subtracted from the elevation of the stake at that point, the result will be the depth of the ditch. Make the proper subtractions and enter results in column 9. Compare results with the values recorded in column 9 of Table XVI.

171. Grade bars. — We have thus determined the depth the ditch must be dug at each grade stake. It is necessary to provide some simple means (1) by which we may know just how deep to dig at every point, and (2) by which we may finish the bottom of the ditch so that the fall shall be constant from one grade stake to the next, above or below. In Fig. 50 are shown what are known as grade bars, more commonly called batter boards. These grade bars are set up over each grade stake, and the top of each grade bar is set at the same height above the proposed bottom of the ditch and horizontally. This height is usually $5\frac{1}{2}$ feet. Some workmen prefer to have it 6 feet, and some would probably have it 5 feet.

172. Boning line and boning rod. — A light strong cord, drawn tight and resting on the tops of these bars, will stand parallel to the proposed bottom of the ditch. If, then, the cord stands above the center of the ditch, and $5\frac{1}{2}$ feet above the desired line of bottom, the workman finishing the bottom can, with a light rod bearing a 5.5-foot mark, by placing the rod on the bottom of the ditch at any point, and holding the rod perpendicular with the

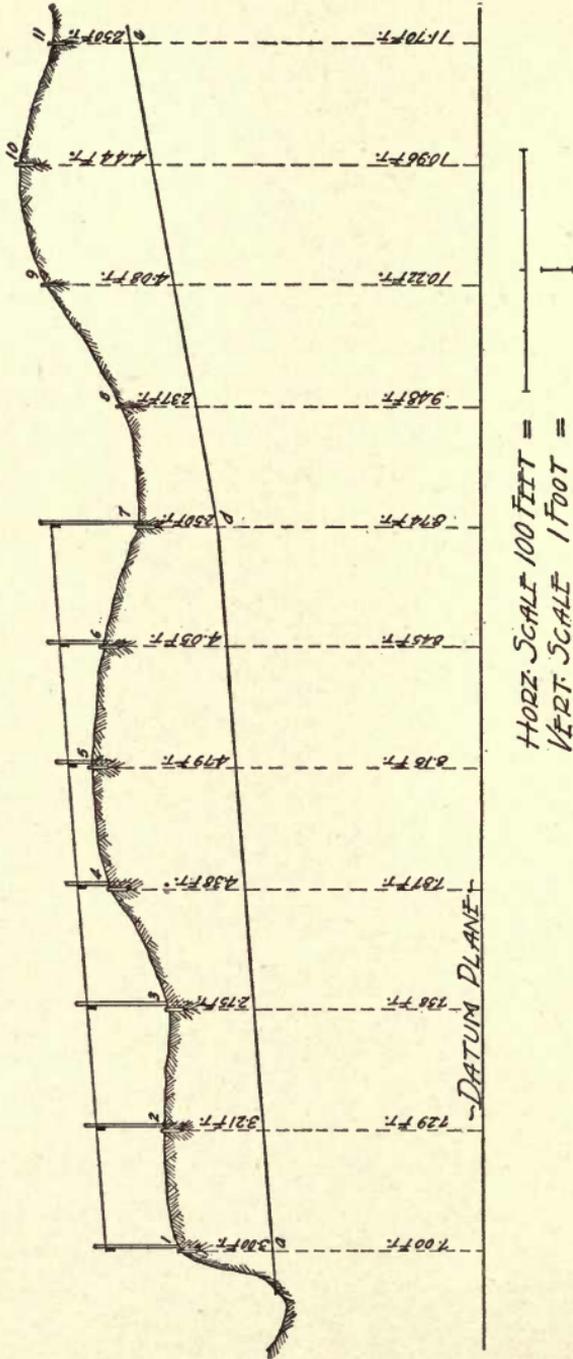


Fig. 50. — Same as Fig. 46, excepting that the grade bars are in place, stakes 1 to 7. Line *ade* indicates the proposed bottom of ditch.

top against the line, tell when he has brought the bottom of the ditch to the proper depth.

173. Determining height of bar above grade stake. — The height of the grade bar above any stake is found by subtracting the depth of the ditch at that stake from the height the line is to stand above the bottom of the ditch (5.5 feet in common practice). These heights are shown in column 10, Table XVI. Verify the figures in column 10 from those in columns 8 and 9.

174. Using the data. — When the work is to be supervised closely by the person developing the data, it is sufficient to rely upon the tables as they are completed. In some cases the depth of ditch, height of grade bar, with the distance of the grade stake from the outlet, and other data, are recorded upon its finder. Sometimes this information is introduced upon the profile diagram used in determining the grade, depth of ditch, and so on or upon one drawn for the purpose. (See Fig. 49.)

CHAPTER VII

CONSTRUCTION

WITH the computations completed, we are now ready to dig the ditch. If up to this point the work has been carefully and accurately done, the work of construction may proceed smoothly. Due care must be exercised in the work that is to follow. No part of the work may be carelessly done, if successful results are to be secured. Proper tools are important, but proper judgment and careful, intelligent work are even more important. Here, again, it must be remembered that this work should be installed for generations of service. Economy in construction must not be overlooked.

175. Ditching tools. — Three tools, especially made for tile ditching, are the ditching spade, tile scoop, and tile hook.

The ditching spade, Fig. 51, is made in different sizes for different kinds of soil. In general the blade is long and narrow, partly to lessen the number of spade depths or cuts necessary to dig the ditch, and partly that the spade full of soil is less likely to slip from the blade in lifting the soil to the surface.

The work of digging and finishing the ditch can be, and often is, done with common spade and shovel, though the tile scoop is desirable for finishing the bottom of the ditch.

The tile scoop, also called drain cleaner, Fig. 51, is used in shaping the bottom of the ditch to receive the tile.

It is made in different sizes, to correspond more or less closely to the size of tile to be laid.

The tile hook is used to lift and properly set the tile in place, and is used chiefly when the operator works from the surface of the ground. It consists of a long wooden handle, carrying a rectangular hook of $\frac{1}{2}$ -inch round iron 10 inches long. (Fig. 52.)

It is desirable also to have a common spade, a common long handle shovel, and sometimes a pick, especially when a heavy clay subsoil or stone is likely to be encountered.

It will be necessary also to have a few hundred feet of strong light cord, a few light sharp stakes 2 feet in length, and material to be used in setting grade bars.

176. Horse and power machines. — There are a number of horse and power machines now on the market that may sometimes be used to advantage in farm drainage. On these, Fippin writes :

“The use of horse and machine powers reduces the difficulty of construction somewhat. If the land is very stony or full of roots, hand labor must be employed, per-

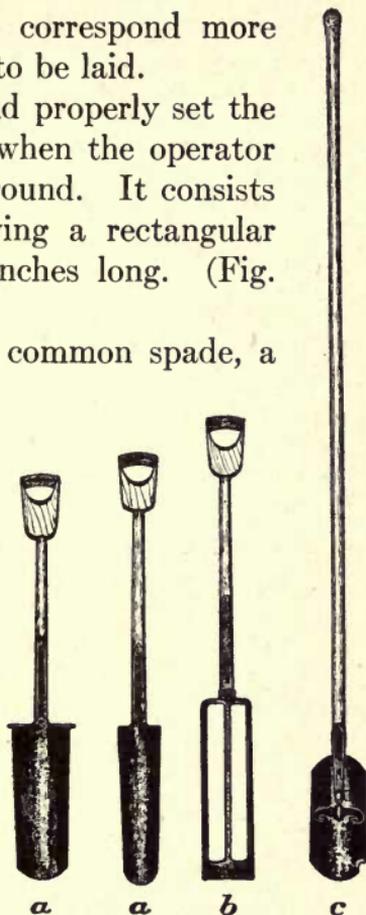


FIG. 51. — Ditching tools. *a, a,* and *b,* ditching spades; *c,* tile scoop, or drain cleaner.

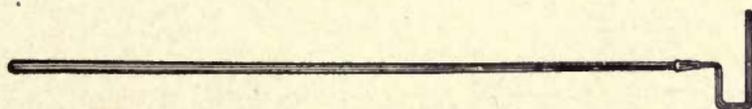


FIG. 52. — Tile hook.

haps with the use of dynamite. On land that is not too stony, the ditching plow drawn by one or more teams is very helpful. There are on the market a number of plows that are very useful for this purpose. Next in complexity is the large ditching plow equipped with wheels and drawn by several teams. This plow tears up the soil and elevates it out of the ditch. There are two or three machines of this type, such as the Cyclone and the Bennett. Finally, there are the large engine-driven ditching tractors, including the Buckeye, the Austin, and the Pawling machines, which cost upward of twenty-five hundred dollars.

“The large plow is suitable for the individual farmer who has a considerable area to drain and has the horses for other purposes. The tractor ditcher costs so much that it is seldom a single farm is large enough to justify its purchase. It may be purchased conjointly by a number of farmers who have drains to be constructed, or it may be purchased by one person and the ditches may be dug by contract. Machines of this kind have been put into several communities for this purpose.”

177. Setting up grade bars. — This is sometimes put off till after the digging is well under way. The objection to this delay is that the grade stakes are likely to be disturbed by the workman when the digging begins.

The grade bar, sometimes called batter board, should be 4 to 6 feet long, of $\frac{7}{8}$ -inch material, with one straight edge. With each bar there must be two stakes, preferably $\frac{7}{8}$ inch by 4 inches, sharpened at one end, and sufficiently long to stand higher, when they are driven into the ground, than the height of the bar at that stake. The two stakes should be driven firmly into the ground, one on each side of the ditch, so that they will stand out

at least one foot from the edge, and so that together with the grade stake, they shall stand in a straight line at right angles to the ditch.

When the stakes are in place, a leveling rod should be set upon the grade stake. Then the grade bar, straight edge up, should be placed against the stakes, with its upper edge at the proper height as measured upon the

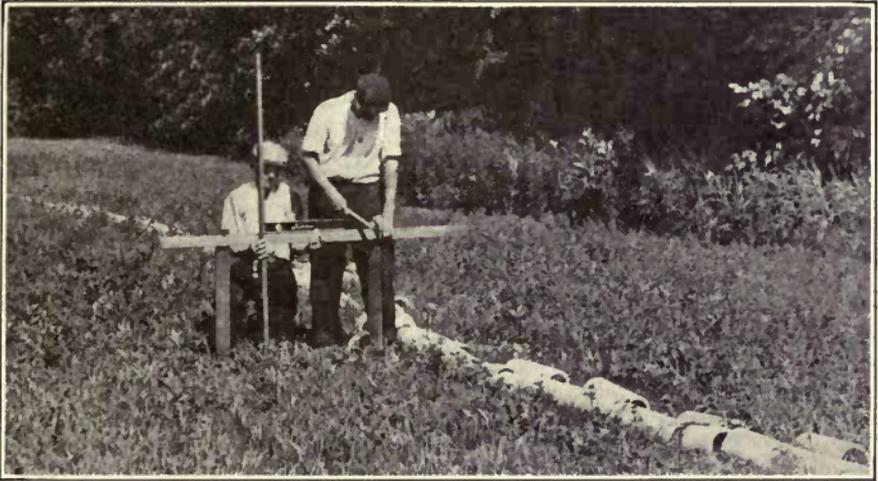


FIG. 53. — Nailing a grade bar in place.

rod. By the use of a spirit level, laid upon the upper edge of the bar, the bar is brought to horizontal and should then be held firmly against the stakes and nailed in place. (See Fig. 53.) All the bars should be nailed upon the same side of their stakes, that is, all facing toward the outlet, or all facing toward the upper end of the drain. The proper height of each bar above its grade stake is found in column 10 of Table XVI.

178. Checking. — When the bars of any section of the drain are up, their upper edges should lie in the same plane, as one sights over them. If the upper edge of any bar

does not lie in this plane, a mistake has been made somewhere, either in the computations or in the work. The mistake should be found at once and corrected. (See Figs. 50 and 54.)

179. Begin the work at the outlet. — The work of digging the ditch should begin at the outlet and should proceed toward the upper end. A careful observation of



FIG. 54. — Showing line of grade bars in place ready for digging to begin. Observe also the tile lying in place. Those in the immediate foreground are the tile for the main.

certain details will undoubtedly make the work easier for the beginner.

180. Opening the ditch. — A line should be stretched about two inches out from the grade stakes to mark the edge of the ditch, and along this line the surface should be cut three inches deep with a sharp spade. The chief purpose of the line is to insure a straight edge for the ditch. This edge should be carefully worked to.

Usually it is not necessary, except with beginners, to stretch a line to locate the other edge of the ditch. The spade should be used to establish it by cutting about three inches into the surface.

Care should be exercised not to open the ditch too wide.

The professional ditch digger seldom opens a 3-foot ditch more than 10 to 11 inches wide, and 16 inches would be abundantly wide for a 6-foot ditch. The wider the ditch, the more soil must be handled. (See Fig. 56.)

181. Removing the soil. — With the edges of the ditch established, the removal of the top soil begins, and in this work a common spade or shovel is generally used, for one cut deep. Several rods of ditch may be opened in this way. The next cut is made with the ditching spade, following the first cut its entire length.

In like manner a second cut will be made, and as many more as may be necessary (using the ditching spade) to bring the ditch to within a few inches of the proper depth. It is usually

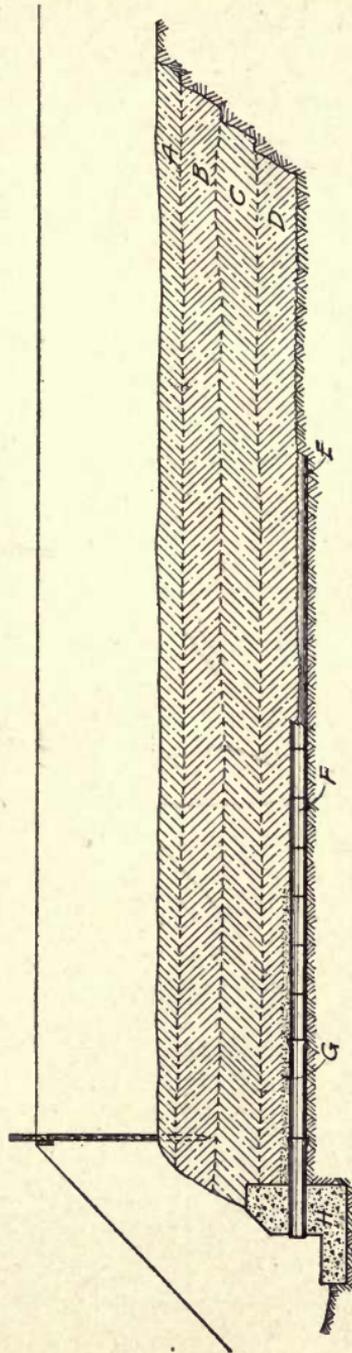


FIG. 55. — Showing steps in the work. *A*, top section removed by shovel or spade; *B*, *C*, and *D*, sections removed with ditching spade; *E*, bottom formed by tile scoop to receive tile; *F*, tile in place, showing also two lengths of sewer tile at the outlet; *G*, "blinding" (loose earth thrown in to hold the tile in place); *H*, concrete protection to outlet. Grade bar and boning line are shown above.

best to throw all the soil to one side of the ditch. Sometimes the top soil is thrown upon one side and the lower soil upon the other.

After any cut, if for any reason a considerable quantity of loose soil lies in the ditch, it should be removed with a long-handled shovel before the next cut is begun, or, if the last cut has been made, before starting to use the tile scoop. (See Fig. 55.)

182. Finishing the ditch. — Before beginning the last cut with the ditching spade, the boning line should be tightly stretched over the top of the bars and just over the straight edge of the ditch, and the rod brought into use to guard against digging the ditch too deep at any point. If in stretching the line, the ends are tied to the end grade bars, braces should be placed in front of the stakes; otherwise the bars and their stakes will be drawn out of place, and the line will be both sagged and lowered. A better way is to drive a stake into the ground beyond the end bars, wrap the line once around each end grade bar, and then tie to the stake just driven.

When the ditch has been dug to within two inches of the bottom, as above described, the line above the bars should be carefully moved out over the center of the ditch, and again sufficiently tightened to remove all sagging. From time to time the line should be examined and, if sagging is resulting from the stretching of the line, it should be retightened. With the tile scoop and rod, a trough or hollow is dug along the center of the ditch and finished so that at all points it shall measure just 5.5 feet below the line. This requires careful work and frequent use of the boning rod bearing the 5.5-foot mark, previously mentioned. (See Fig. 56.)

183. Correcting depth. — If at any point too much earth is removed and the ditch made too deep thereby, a sufficient amount must be returned and carefully molded into place with the scoop, to bring the bottom up to grade. The less the fall, the greater is the care that must be exercised in finishing the bottom. This part of the work is not difficult, although it requires care and judgment. It is sometimes done from the surface. Usually, however, the workman stands in the ditch.

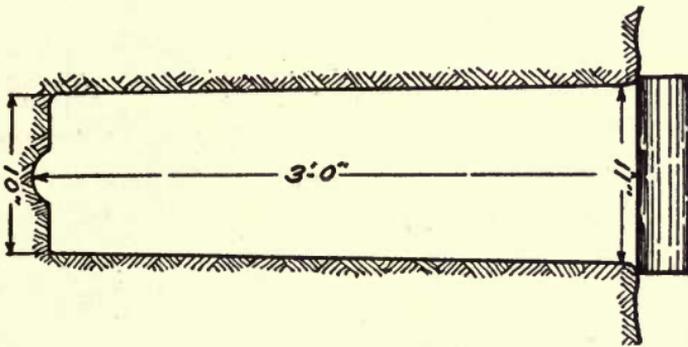


FIG. 56. — End section of ditch, showing in diagram the bottom of ditch formed to receive the tile. Note the width of the top of the ditch as compared with the 12-inch length of tile resting on its edges.

184. Laying the tile. — The laying of the tile should begin at the outlet and proceed toward the upper end. It is usually best to lay the sections of tile as rapidly as the bottom of the ditch is made ready with the tile scoop to receive them. Some workmen lay the tile by hand and some use the tile hook; some stand upon the surface to finish the bottom of the ditch and to lay the tile.

185. Making close joints. — It will be found that the ends of the tile are frequently not square, — are not at right angles to the sides, and that the tile is sometimes warped, or bowed, thus throwing the ends out of square. There are sometimes little inequalities in the bottom of

the ditch. Because of these three facts it will be found that if a lot of tile is laid promiscuously, end to end in the hollow at the bottom of the ditch, many of the joints will be so open that sand will very readily drop through into the tile drain; consequently if the tile are left in this position, and the ditch filled, the drain will be clogged in a very short time. There should be no open joints.

“The tile is sometimes clogged by the development of roots that gain entrance through the joints of the tile. The depth at which the tile are laid has very little to do with this difficulty. It is determined by the presence of a perpetual flow of water in the tile from some spring. In dry periods this water seeps from the joints and moistens the soil, which condition attracts the roots. Protection of the upper half of the joint against the admission of silt is some aid in preventing the entrance of roots into the tile.” — FIPPIN.

186. Fitting the joints. — If, when a section of tile is laid in place, it does not fit tightly against that already laid, it is usually found that by rolling it to the right or left, it can be made to fit so tightly as practically to prevent the passage of soil particles except quicksand or fine silt. Sometimes this cannot be done, in which case a new piece of tile must be substituted. A piece that cannot be made to fit in one place will frequently readily fit in another place in the same line of tile.

187. Blinding. — As the work of laying the tile progresses, the workman should shovel in a sufficient amount of loose soil to settle down about the sides and partly, or wholly, cover the tile. This holds the tile in place until the filling can begin. Sometimes, instead of shoveling in the soil from the surface, some earth is loosened from

the walls of the ditch to fall upon the tile and accomplish the same results. This covering and anchoring of the tile is called blinding. (See Fig. 55.)

188. Closing the upper end of the drain. — When the last tile of any drain is laid, a stone, or piece of brick, or pieces of broken tile, or other solid material should be laid against the upper end and earth shoveled against it to hold it in place. This, later, prevents the soil from working into the end of the tile.

189. Filling the ditch. — The filling may proceed as rapidly as the tile are laid and anchored. It may be deferred a few days, or several days, depending upon circumstances. Delay is likely to result in caving of the walls. In the cases of mains or sub-mains, the complete filling is delayed until the laying of the tile in the laterals is started. Usually the grade bars are removed before the filling begins. Sometimes the filling is done by hand; sometimes it is hastened and cheapened by the use of the plow or scraper. When a plow is used, an evener must be provided that is sufficiently long to allow the horses to walk on opposite sides of the ditch. When the plow is used, the bars and stakes must first be removed. The team is driven the length of the ditch, or for a considerable part of it at a time, and the soil is plowed back into the ditch.

Only the board scraper is convenient for filling. The team works on one side of the ditch and the man and the scraper on the other. A chain or rope must be used between the team and scraper, which must be long enough so that the team shall not be backed sufficiently near the ditch to result in accident.

When the plow or scraper is used, it is usually necessary for a workman with a shovel to finish the work.

190. Finishing the outlet. — The outlet of the main should be completed with two objects in view:

1. Provision should be made against its destruction by frost, flood, tramping of live-stock, and the like.

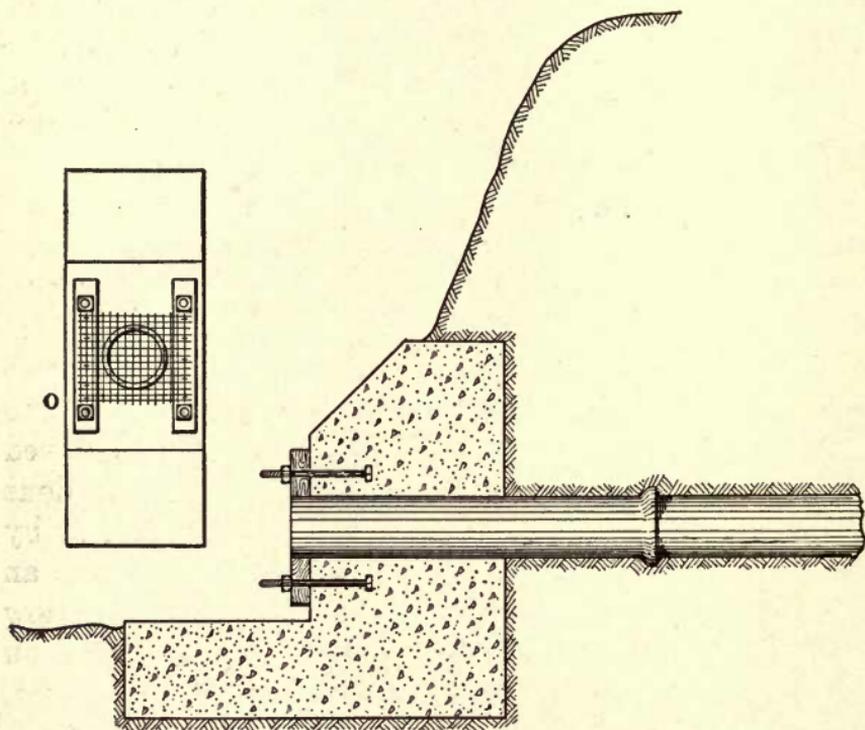


FIG. 57. — Showing the way in which bolts may be imbedded in the concrete or other outlet protection by which strips of wood may be bolted in place to carry screen to protect mouth of outlet from vermin, etc. This shows piece of screen nailed over the outlet. The width of face of outlet will depend much upon the nature of the soil, height, and slope. The face in this figure is but 18 inches wide. Ordinarily the face proper should probably range from 30 to 60 inches.

2. Usually it is best to replace the lower 8 to 12 feet of tile with glazed sewer pipe, or with a piece of cast-iron pipe of proper size. (See Fig. 55.) This should be done, of course, when the work of laying the tile begins.

To prevent the washing or tramping of earth about the outlet, and to give strength, a wall of masonry or concrete should be built something as shown in Fig. 55.

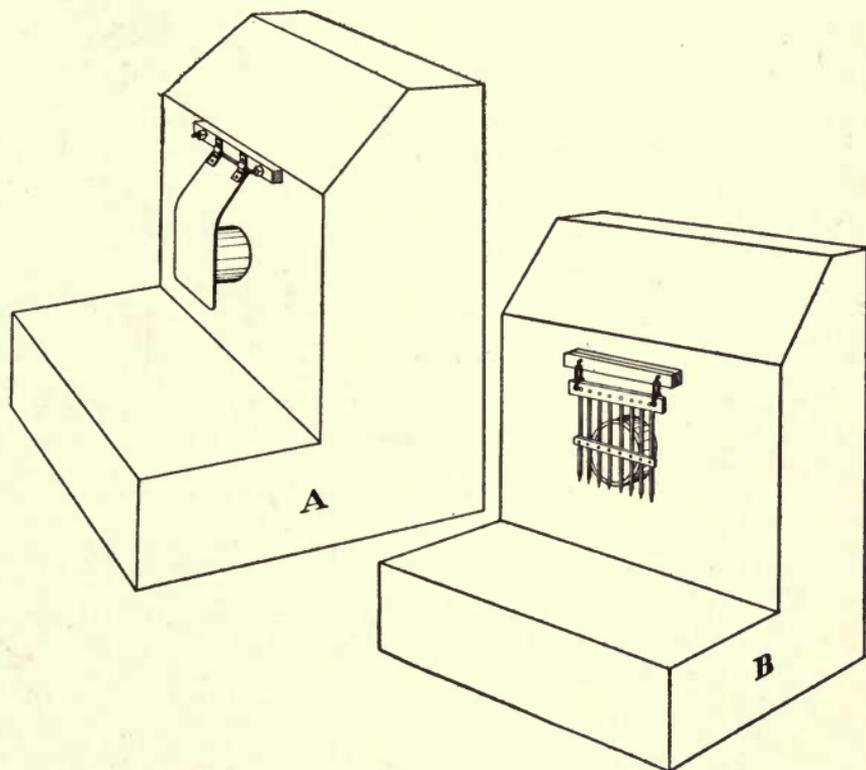


FIG. 58. — Two devices for protecting drain outlets. *A*, trap of galvanized iron hung by common door hinges. The serious objection to the trap is that it interferes with the entrance of air to the tile system. *B*, screen of $\frac{1}{4}$ -inch iron rods, hung, in this case, by chain links. Devices of this nature are especially desirable when surface water is let into the tile system.

191. Screen. — Means should be provided to prevent vermin, such as rats, from entering the mouth of the drain. To accomplish this, a screen of woven wire, or a grate of iron bars mounted on or in a strong wooden frame, should be firmly set against the outlet. (See Fig. 57.) It will

be well, in building the cement work, to set in bolts to hold the frame carrying the screen or bars in place, as shown in Fig. 57.

192. Trap. — A trap of galvanized iron, like that shown in Fig. 58, will prove effective. A better device is that of a screen of $\frac{1}{4}$ -inch iron rods suspended by hinge or chain links. The hinged trap or screen is especially desirable when surface water enters the tile above, by way of silt-basins or otherwise.

193. Laterals. — As has already been stated, the work of placing laterals does not differ materially from that of laying single lines of tile or mains. The leveling is done in the same way, excepting that usually the lateral connects with the main at one of the original grade stakes. This is not necessary, but it is convenient. This grade stake becomes stake 1 of the lateral, and its elevation as determined for the main is retained as that of stake 1 of the lateral. This is desirable since by it the elevations of all points in the system are referred to the same datum plane, and a basis is thus given for comparing the actual elevation of the lateral, or any point in the lateral, with any other point in the system.

194. Leveling for laterals. — The leveling for the laterals is often done immediately after that for the main is completed. Sometimes it is deferred till the work of digging and laying the tile of the main is nearly finished. In the former case the levels for a lateral may help to determine the proper depth of the main, and may thus increase the efficiency of the lateral. In the latter case, the danger from inaccuracies, due to disturbing grade stakes along the laterals after the leveling has been done, is greatly lessened.

The depth of the outlet of the lateral is determined by

the depth of the main at the point of connection. (See paragraphs 197–199.) This fact may modify both the grade and the general depth of the lateral.

195. Making provision for lateral outlet when laying the main. — As the digging of the main proceeds, and as the tile are laid, provision should be made for the outlet

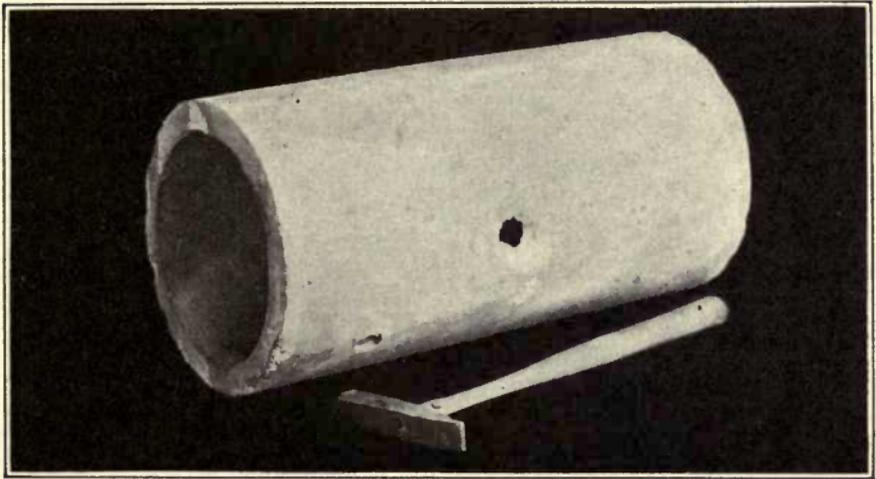


FIG. 59. — Five-inch tile with small opening, and hammer used in making the opening.

of each lateral. The connection should be introduced and an obstruction placed over the outer end till the laying of the lateral is begun.

196. Joining laterals to mains. — Mention has already been made of the angle at which the laterals should be brought to the main. Three general methods of making connections are suggested; namely, side, top, and angle connection.

197. Side connection. — By the first method the lateral discharges into the side of the main. In this case the center of the lateral should come even with the center of the main. This means that if the lateral has a smaller

diameter than the main tile, the bottom of the lateral ditch must be planned to approach the bottom of the main ditch at a height of one-half the difference between the outside diameter of the main and of the lateral tile.

To make connection, a hole should be picked in the wall of the main at the proper point (see Fig. 59), and made of sufficient size and shape to permit the entrance of the

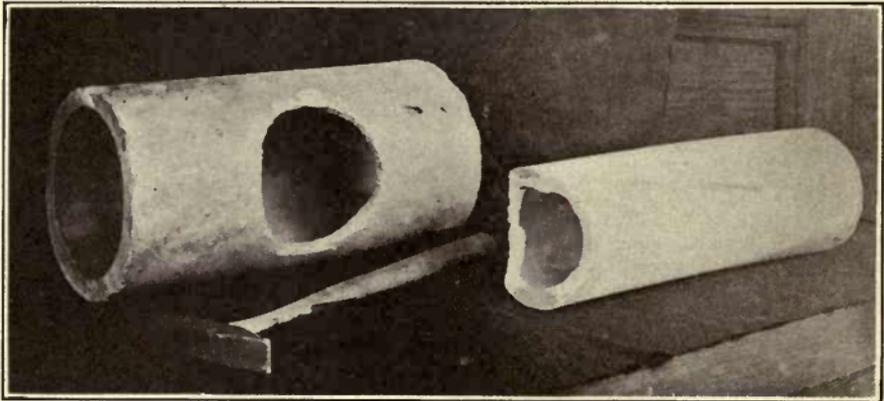


FIG. 60. — Five-inch tile shown in Fig. 59, with the opening enlarged to receive 3-inch tile. The 3-inch tile is shown with end shaped to set in the opening in the larger tile. In this particular case the opening and trimming are done for a 90-degree connection. A 60-degree connection would require a larger opening and more trimming of the 3-inch tile.

lateral tile at the proper angle. The end of the lateral should be rounded back and shaped so that the end, when the tile is in place, shall stand flush with the inner wall of the main. (See Figs. 60 and 61.) When the lateral thus fitted is set into place, fragments of broken tile should be carefully laid in over the joint and earth packed about it. This is to prevent the working in of soil material.

198. Top connection. — By the second method, the lateral discharges its water down through the top of the

main. In this case an opening is made through the top of the main and through the bottom of the lateral. In digging the lateral ditch, the bottom should stand sufficiently high above that of the main ditch, so that the center of the lateral tile shall stand even with the top of the inside diameter of the main tile. The end of the lateral tile should project over the main and should be plugged to prevent the entrance of soil material. (See

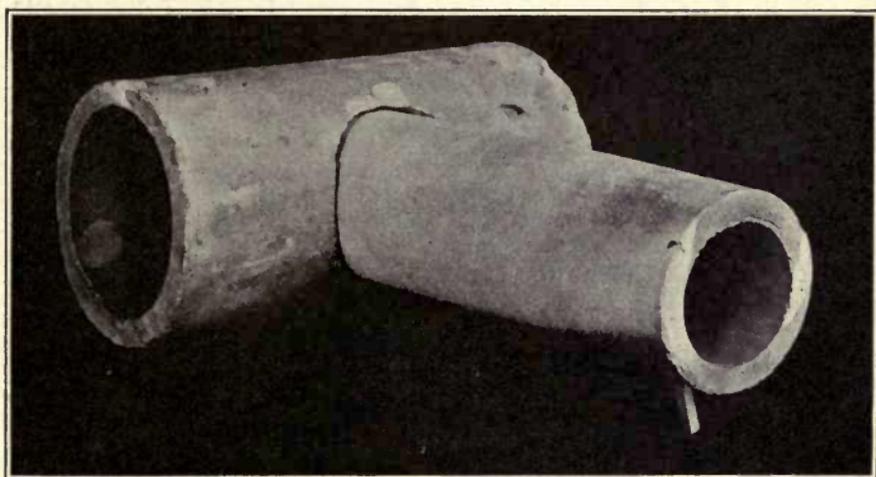


FIG. 61. — Shows the connection when the 3-inch tile is fitted in place. It will be observed that the connection is a 90-degree connection.

Fig. 62.) The same precautions should be taken as indicated above to close the joint sufficiently to prevent the soil from working through.

199. Angles. — Some manufacturers of glazed tile are now manufacturing, also, angles and T's in various sizes for making connections between drains. When these can be secured they are desirable, since they reduce labor and insure good connections. In most cases these would be side connections. (See Fig. 63.) The difference in elevation of bottom of main and that of the con-

necting lateral will be governed, as above, by the sizes of tiles used.

200. Making openings through tile. — An opening through the wall of a section of tile is easiest made with

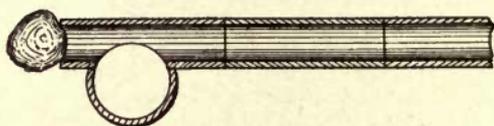


FIG. 62. — A top connection in cross-section. A stone closes the lower end of the lateral.

what is called a tile pick. With care the opening can be made with a small-headed hammer, such as is shown in Fig. 59, by first knocking a small opening in the wall about where the center of the finished opening should be, and then carefully chipping away the edges of the opening by light blows with the hammer until it is made suffi-

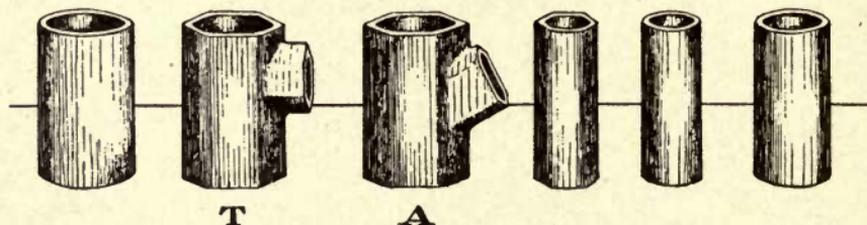


FIG. 63. — *A*, a vitrified 6-inch tile with angle for connection for 4-inch lateral. *T*, section of 6-inch vitrified tile with *T* for 4-inch connection. The other sections are of common tile.

ciently large. A small hammer is much to be preferred to a larger one in this work. The larger the hammer, the greater the danger of cracking the tile from the jarring. With the smaller sizes of tile, the section should be held in one hand while the opening is being made with the hammer. (See Figs. 59, 60, and 61.)

201. Designating the sub-mains and laterals in the

records. — In keeping field notes it is desirable to have some definite method of indicating mains, sub-mains, and the several laterals. The main is usually designated simply as main. If there is more than one system of tile drains on a farm, the systems should be numbered or lettered, so that the main of any system would be indicated, main of "system A" or "system 1." A sub-main is simplest designated by the stake in the main at which it discharges its water. If a sub-main united with a main at stake 5 of the main, it would be designated as "sub-main 5." A lateral is simplest indicated by the stake of the sub-main or main at which it empties its water. A lateral uniting with a main at stake 11 of the main may be designated "lateral 11." A lateral emptying its water at stake 13 of a sub-main would be designated lateral from stake 13 of sub-main, if there was but one sub-main; if more than one, the number of the sub-main would need to be indicated. (See Table XX.)

CHAPTER VIII

OTHER CONDITIONS AND PROBLEMS

VARIOUS questions arise in the course of the installing of a tile system. In many cases the problem will suggest its own solution. In other cases, solutions can be offered only by those who have theoretical knowledge of conditions or who have had a large practical experience. The science and art of drainage have been matters of growth, and of rather slow growth. There are many questions yet to solve. A few of the more common questions will be discussed in this chapter.

202. Underground outlets. — It sometimes happens that a low area requires draining but has no outlet through which the water can be taken off, or is surrounded by ground so uniformly high as to make it expensive, or even impossible, to secure a proper outlet. Not infrequently it will be found that the soil of this low area is underlaid by a heavy clay, and that the clay in turn is underlaid by an open gravel, or an open gravelly sand, in which the water-table stands at a considerable distance below the clay. Under such conditions, if a well three feet in diameter is dug through the clay into the gravel, all the water from this low area may be drained into the well, and from this well the water will disappear down through the gravel. The well should be dug to a depth of at least one foot below the clay, and should be filled with field stone to above the point where the outlet of the drain

is turned into it. The top stones should be small, and upon these should be placed gravel, then sand, then the regular soil of the field. The writer has in mind one such arrangement in which a tile system, draining something like 160 acres, discharges its water and has been in successful operation for many years. In depressions of limited area, such a well at the lowest point and with the stone coming to the top is frequently sufficient to carry away the excess of water without the aid of tile. (See Figs. 64 and 65.)

203. Drain heads. —

Instead of constructing a well, as above described, the practice is becoming somewhat general of installing a vertical system of tile. Six-inch tile are usually used, and upon these is sometimes set what is known as a drain head, a device rather commonly advertised in agricultural papers. When the vertical tile system is used, the horizontal drains are dispensed with. Instead, a number of vertical systems are introduced, if one is not sufficient to drain the whole area.

204. Drainage by wells. — Vertical drainage, probably beginning in formations of drift origin, has been extended to soils overlying other than drift deposits.

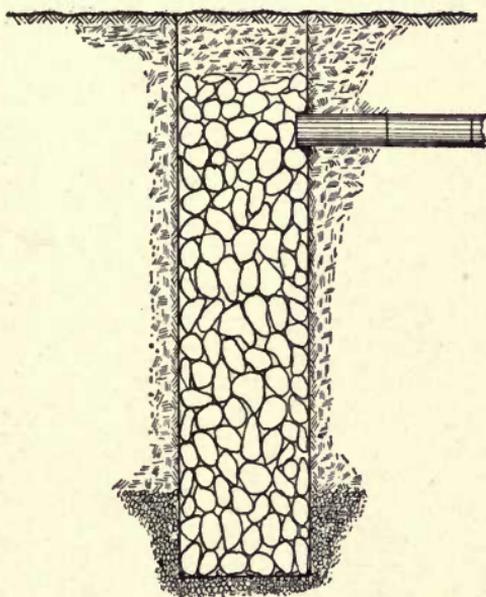


FIG. 64. — The way of constructing well for drainage downward into underlying gravel.

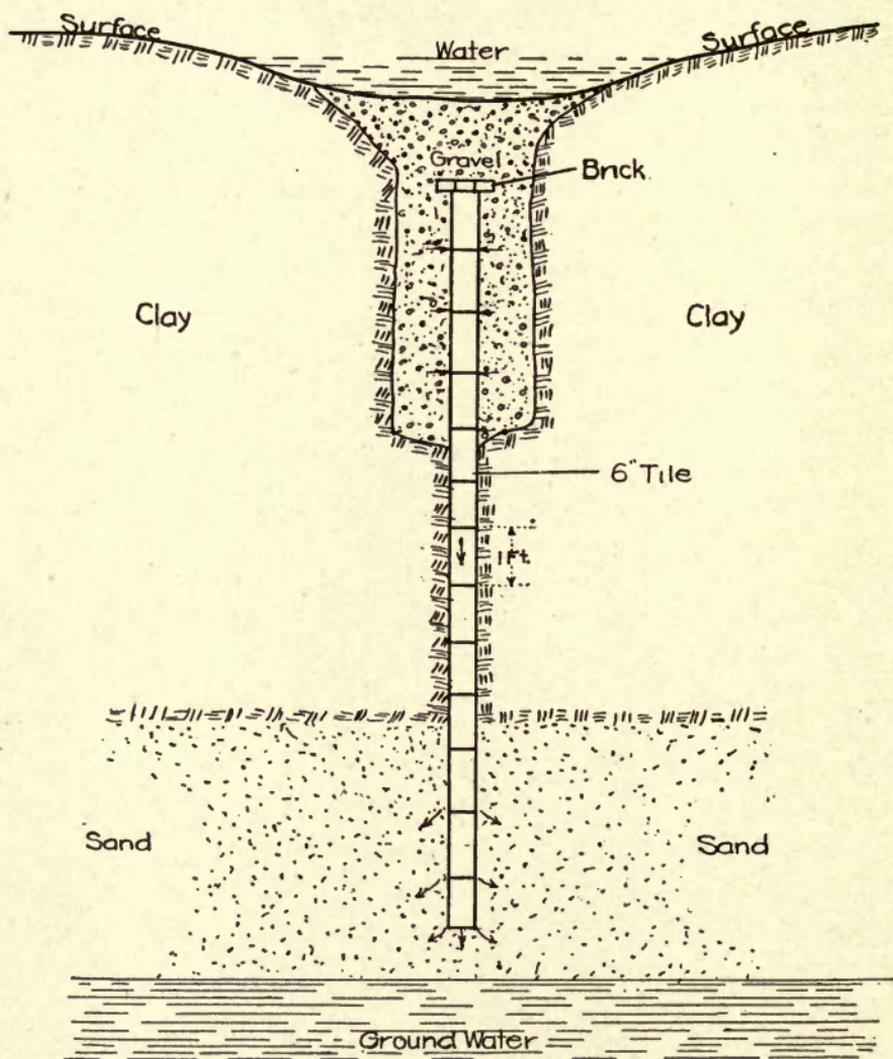


FIG. 65. — Plan, described in Bulletin 229, Wisconsin Experiment Station, for removing drainage water by means of a gravel-filled well and tile.

The following facts are gathered from one of the Water Supply Papers of the United States Geological Survey.¹

¹ Fuller. Water Supply Paper No. 258. 1910. U. S. Geol. Survey.

In Michigan and Minnesota, drainage outlets are secured by way of wells drilled into sandstone; in Georgia, Indiana, Kentucky, Tennessee and Virginia, and other states, by the use of drilled wells in limestone.

The efficiency of such a drainage well is usually dependent upon the depth of the well. It is dependent also upon the nature of the material; for it varies with the same material. In gravelly sand and sandstone the size of the openings (pore space) rather than the percentage of pore space is important. In limestone the size of crevices is the important item.

205. Quicksand. — It sometimes happens that quicksand is encountered at or near the bottom of the ditch in

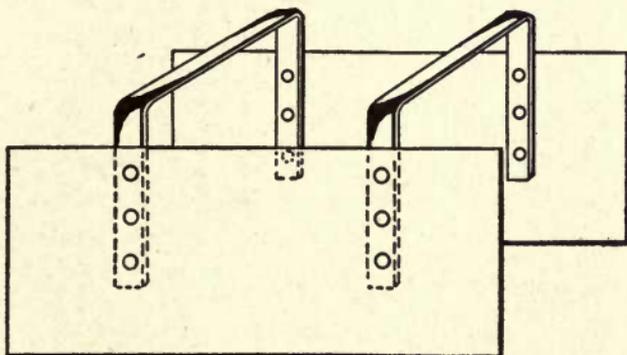


FIG. 66. — Steel shield used to hold back quicksand; 28 inches long, 12 inches high, width governed by size of ditch.

laying the tile. In such case it will usually be necessary to use some kind of guard to hold back the quicksand while the bottom of the ditch is being completed to receive the tile. Figure 66 shows a shield of iron used for this purpose. In the use of the shield, the ditch is dug to the quicksand. The shield is then placed so as to include that portion of the ditch in which the next sections of tile are to be laid. The workman can usually press it down into the quick-

sand by his own weight sufficiently to bring it even with or a little below the bottom of the ditch when it is complete; or if his weight is not sufficient, he may remove a portion of the sand and then place his weight upon the shield and lower it little by little to the bottom of the ditch. With a tile scoop, the bottom of the ditch can then be properly formed and the tile laid in place. The shield is then lifted and moved ahead sufficiently to prepare the bottom for the next section. It would not be difficult to make a shield of wood that could be operated in much the same way.

Where the ditch is deep and the quicksand is found to stand to some height above the bottom of the ditch, planks or boards should be used to hold the banks from falling in and great care should be taken to avoid accidents from caving.

206. Protection to joints against quicksand. — When tile is laid in quicksand or in very fine ordinary sand or silt, it is usually necessary to provide some means to prevent the fine particles from entering the tile through the joints. It is sometimes recommended that marsh hay be laid over the tile before any soil is introduced into the ditch. Strips of strong building paper are sometimes laid over the joints before the earth is introduced. An inch or more of top soil or fine clay, laid over the joints, will prove fully as satisfactory as grass or paper, and much more enduring.

207. Boggy and springy places. — Sometimes in laying tile through muck soils, springs are discovered which cause such a degree of softness in the muck at the bottom of the ditch that it is very difficult to lay the tile with any degree of evenness. In such cases it is recommended by successful drainage engineers that the ditch be dug

sufficiently deep to lay a six-inch board in the bottom so that the upper surface of the board shall lie at the proper depth and upon this the tile be laid and the earth introduced about the tile. Boards thus used will resist decay for many years.

208. To remove excessive surface water. — It sometimes happens that the topography of a tile-drained area is marked by depressions which, in times of heavy rain, become filled with surface water. This means that an amount of water which, if distributed uniformly over the drained area, would be removed in reasonable time by the tile system, must, because of the relatively greater quantity over a restricted low area, require an unusual or extended time to make its way through the soil to the drains. The result may easily be the drowning of a crop, injury to the structure of the soil, the washing away of plant-food, or the destruction of food by denitrification. Again, a tile-drained area may lie subject to the overflow from surface drainage from adjacent higher areas, or adjacent slopes, and therefore to the same consequent ills as those named above. Both Elliott and Waring suggest provision for the quick removal of such surface water by ducts, or other means, by which the surface water is conveyed below ground to the tile. Wherever, in an area to be tile-drained, surface depressions occur, in which the surface water may gather in large quantities, the system should be planned so that a main or lateral crosses it. If a lateral crosses the area, and the area is of considerable size, the size of the tile in the lateral should be larger than that used in the ordinary lateral of similar length.

To provide means for the passage of the water from the surface to the tile, one of the schemes suggested is to lay

the tile, for 3 to 8 feet, with the upper joint very open, and then to fill the ditch with broken stones of 3 to 4 inches in diameter, or with cobble stones of the same dimension. Another is to construct a shallow silt-basin of rather large diameter to receive the excess of surface water, with a siphon to remove this water to the tile below. A shallow open ditch gathers the surface

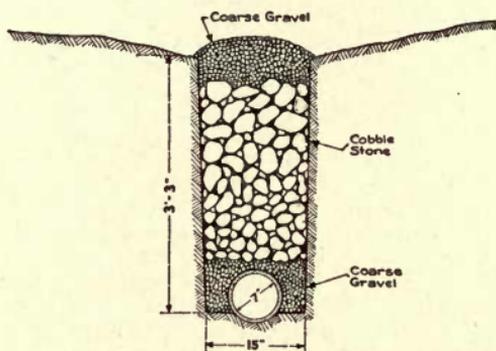


FIG. 67.—Plan for permitting excess of surface water to reach tile drain by filling a section of ditch with crushed stone or cobble stone.

water and delivers it to the silt-basin. (See Figs. 67 and 68.)

209. Tile in muck soil should be laid deep.—Muck soils settle rapidly after they are tile-drained. This settling is due, in part, to a natural shrinkage because of the reduction of moisture present, and probably to chemical changes which take place because of the more ready access of air to the organic material. These changes are commonly spoken of as oxidation. In the course of a few years, the surface of a tiled muck area may have settled until the tile lies within the frost zone, and not infrequently lies so near the surface as to be disturbed by the plow-point. The effect of freezing is to shale the tile, if of the ordinary clay kind, even to the extent of causing them

to collapse. One considerable area of muck soil on the Michigan Agricultural College farm had so seriously settled in this way in twelve years, that the tile in the whole area had to be relaid. Except where truck-farming is practiced, therefore, tile should be laid more than three feet deep in muck soils, if outlet conditions will permit.

210. Gravitational water in irrigated lands. — Much

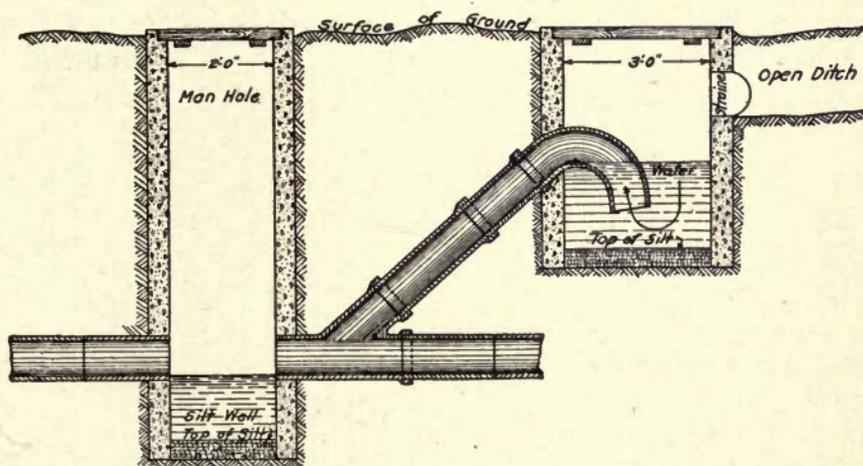


FIG. 68. — Plan for moving surface water by way of silt-basin and the tile system, adapted from Bulletin No. 199, Wisconsin Agricultural Experiment Station.

has been said and written of the injury done to lands by seepage waters. It has almost invariably been charged that these waters, coming from higher areas, where they have been used in excess to water lands, or by seepage from supply canals, passing down or out to lower areas, become charged with alkali salts; that, as they come to the surface of these lower areas, and evaporate, they leave their burden of salts to incrust the surface and later to work injury or death to crops planted thereon. In 1890 Shaler described the destruction of the very fertile area

adjacent to the Jordan River in Utah, by seepage waters from higher adjacent irrigated areas.¹ In a similar manner it was charged that the raisin grape industry in the vicinity of Fresno, California, was ruined.²

Extended areas of vineyard have been discarded and planted to grasses, which contribute some feed to dairy animals. Land values of these orchards have fallen from \$350 to \$15 an acre. The destruction of the vines was charged to the presence of alkalis. Investigation has shown that the ground water now stands within three feet of the surface. A recent investigator says: "But it is clear that the alkalinity of the soil alone would have done little damage had it not been for the rise of ground water so near to the surface. Sixty thousand acres have thus been affected. It has been found that this same difficulty occurs in irrigated areas where the presence of alkalis do not exist in injurious amounts. It is admitted, however, that where alkali salts do occur in seepage ground waters, they undoubtedly do injury, and especially from the incrustations resulting from surface evaporation, and that this incrustation may be so severe as to require heavy flowing of water for a few times in irrigating. It has been found that where drainage methods can be established, and the ground water lowered, even a few feet, beneficial effects are quickly apparent."

The installing of tile drains on such lands will not differ materially from that in other lands. The following facts are offered:

It is not advisable to use less than 4-inch tile for

¹ Part 1, 12th Annual Report, United States Geological Survey.

² Bulletin 217, Office Exp. Station.

laterals, and all tile should range larger than for similarly placed tile in ordinary systems in humid regions.

Tile should not be laid, generally, less than 4.5 feet deep.

The fall in any case should not be less than 0.1 foot for 8-inch tile and 0.2 foot for 4-inch tile.

Long lines of tile should be avoided. Silt basins should be installed at frequent intervals.

Flooding is frequently necessary to remove accumulations of salts, and where hard pans exist, blasting is frequently necessary to facilitate the leeching.

The drainage waters of most of these systems must be lifted by pumps.

Tile drains under orchards, vineyards, and other perennial vegetation are subject to clogging from roots. When installing such a system, provision should be made for the future cleaning of the drains. Silt basins should be placed at reasonable intervals, and in each line between basins there should be placed, when laying the tile, a small steel cable. When evidences of root clogging appear, a steel brush of proper size is hitched to (usually) the lower end of the cable and drawn through the line of tile. A second cable is first attached to the brush to be drawn through after it to replace the cable thus pulled out. A frame carrying a pulley set opposite the opening of the tile drains should be placed in silt basins to carry the cable and prevent its injuring the tile.

Tile drains are likely to clog if water-table is permitted to remain too high.

211. Cost of tiling. — The cost of tile and of hauling and distributing it are matters that can be fairly easily determined for any particular job. The cost of tile laid down at the nearest station will depend upon its distance from the factory. The cost of hauling will depend on the dis-

tance of the farm from the station and the condition or quality of the roads.

The cost of digging the ditch, laying the tile, and filling the ditch is subject to considerable variation due to the nature of the soil and the cost of labor. Elliot estimates that where: (1) the earth is readily spaded and no pick or bar is required in the digging, and (2) the wages for good diggers is 25 cents an hour and for expert ditchers is 35 cents an hour (the last representing half the labor required and including superintendence), the cost of digging the ditch, laying the tile, and blinding will approximate the figures shown in the table below :

TABLE XVII

APPROXIMATE COST TO A ROD OF DIGGING DITCH, LAYING TILE, AND BLINDING UNDER CONDITIONS NAMED ABOVE

DEPTH OF DITCH	FOR 4-INCH, 5-INCH, OR 6-INCH TILE	FOR 8-INCH TILE	FOR 10-INCH TILE
2 feet	25 cents	34 cents	42 cents
2½ feet	28 cents	38 cents	47 cents
3 feet	32 cents	42½ cents	53 cents
3½ feet	35 cents	48 cents	60 cents
4 feet	40 cents	54½ cents	68 cents
4½ feet	45½ cents	62 cents	77 cents
5 feet	52 cents	70 cents	87 cents

When the ground is so hard as to require a considerable use of the pick or bar, the cost may reach double that indicated in the table.

The filling of a 3-foot ditch will cost three cents a rod when a team and plow or scraper are used, or six cents a rod when performed by hand labor. The cost of filling

other sizes will vary from these figures according to the depth and width of the ditch, and will be about proportional to the cross section of the ditch.

A workman, reliable and expert in laying tile, and who did most of the work "by the rod," estimated that he could dig a 3-foot ditch, lay and blind the tile (3-inch and 4-inch), as follows :

In clay soil, requiring some "picking"	6 rods a day ;
In sandy or loam soils	9 rods a day ; and
In muck soils	12 rods a day.

In Lenawee County, Michigan, a common practice has been to charge by the foot for digging the ditch and laying the tile. When the drains average 3 feet deep, the price is 1½ cents a foot for laying different sizes up to and including 4-inch tile, while the price is 2 cents a foot for 5- and 6-inch tile. Above 6-inch tile, wages are usually paid by the day.

212. Order of steps in tiling. — If the following order is observed in installing a system of tile drains, numerous difficulties may be obviated :

1. Study the ground.
2. Establish the outlet.
3. Locate the main.
4. Determine the number and locate the lines of the laterals.
5. Estimate the amount and kind of tile required and place order.
6. Place the grade stakes with finders, if that has not already been done.
7. Haul and distribute tile.
8. Do the leveling, at least for the main. The leveling

for the sub-mains and laterals may proceed just sufficiently rapidly to keep in advance of the digging.

9. Make computations.
10. Set up grade bars.
11. Do the rough digging, following closely with
12. Finishing the bottom, laying the tile, and blinding.
13. Fill.

CHAPTER IX

THE HOSE-LEVEL

THE author has recently used a simple device for drainage leveling with excellent success. This device is shown in Fig. 69. It consists of a piece of garden hose, with a water gauge tube tightly inserted in each end, and the ends held up. Water is carefully introduced into the hose halfway to the top of the tubes. When proper care is exercised to prevent the presence of air bubbles in the water in the hose (and this is easily accomplished), and when the upper ends of the tubes are open, the two columns of water stand at the same height (or level) no matter how irregularly the hose may lie upon the ground or other surface. "Liquids seek their level." (See Fig. 70.)

213. Accuracy of reading. — Far greater accuracy in reading can be obtained with this device than with any of the so-called cheaper levels; and so far as he has used it, the author

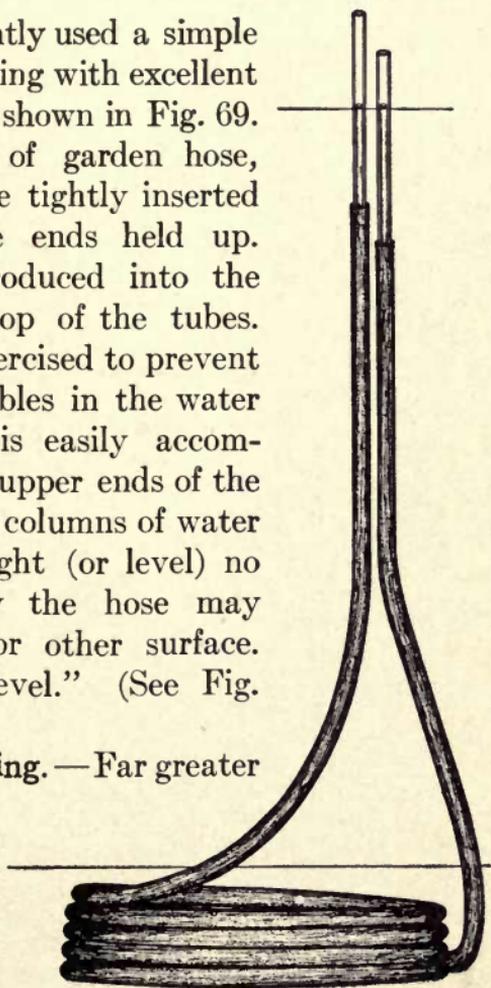


FIG. 69. — Hose-level.

has been able to check as closely with it as with the higher-priced instruments. It is sometimes used by architects and builders for checking up the level of foundations for large buildings, and in leveling shafting where an intercepting wall prevents the use of the ordinary level. As a drainage level, its chief limitation is that the distance over which a single reading may be taken is relatively short.

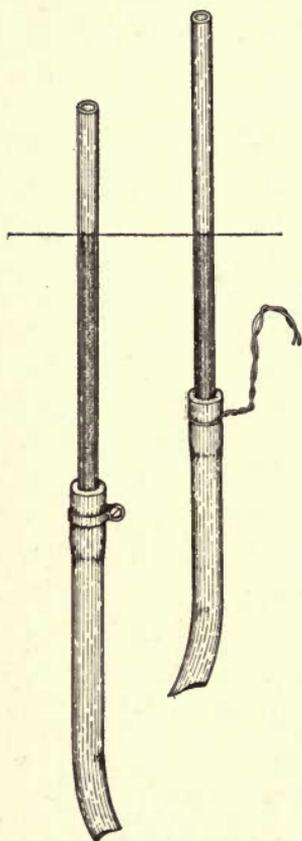


FIG. 70. — Ends of hose-level, showing the way in which the height of column should be read. The meniscus in each case, that is, the upper end of the water in the tube, is U-shaped. The reading should always be made to the bottom of this U or meniscus.

214. Availability and cost. — Garden hose is readily obtained in most towns and villages. Indeed it is used on many farms, so that frequently it is already owned or is easily obtained by the party desiring to use it to construct a level. Water gauge tubes, twelve inches long, are not difficult to obtain through the local hardware man, who is likely to have them in stock.

215. Materials needed. — To construct a hose-level one should have the following material:

Sixty feet of garden hose;

Two 12-inch glass water gauge tubes;

A few feet of strong copper wire or flexible steel wire to close tightly the ends of the hose about the gauge

tubes, and form a hook at each end of the hose by which the end may be suspended when not in use, or for other reasons;

A good pair of combination nipper pliers for handling and cutting the wire, and so on ;

A few gallons of clear water free from oil, sediment, and the like.

216. Suggestions. — Half-inch hose is preferable to a larger size.

Sixty feet of hose is sufficient where the grade stakes are not over 50 feet apart.

The gauge tubes should have an outside diameter sufficiently large to cause them to fit fairly snugly in the ends of the hose.

The gauge tubes should have the same inside diameter. If they differ materially, the water will rise higher in the tube having the smaller inside diameter.

There are to be procured on the market, at reasonable prices, coupling-clamps, which are simple and easier to use than wire in closing the ends of the hose about the tubes.

217. Constructing the hose-level. — A tube should be inserted in one end of the hose and firmly clamped. If wire is used to clamp in the tube, the piece should be cut long enough so that after the clamping is accomplished, the end of the wire may be bent into a hook, by which to hang up the end of the level. If a coupling clamp is used to close the hose about the tube, the wire hook should be provided also.

It is best not to insert the tube at the other end till after the hose has been filled with water ; but wire and tube (or clamp and tube and wire) should be made ready to complete the end, as in the former case, as soon as the hose is filled with water.

218. Introducing the water. — Before starting to fill, it is desirable that the hose be stretched straight upon

an even surface — ground or floor — preferably upon a slope or incline, and parallel to the slope. The upper end, with tube inserted and clamped in place, should be suspended, or held, tube up, about three feet above the floor.

The water should be introduced at the lower end (first removing the tube if it has been inserted). At first the end should be held low while the water is being introduced. The water should be poured in slowly, with a care not to introduce air with it. As the filling proceeds and the water fills the hose, the end should be raised until the hose is filled to the upper tube. The tube should now be inserted at the filling end and clamped in place, and enough more water added to bring the water to about the middle of both tubes, which means, of course, that the tubes must be brought to the same level.

The hose could be better and more quickly filled if an end could be tightly fastened over the end of a water tap, having water free from air, and with some pressure. In this case the water should be allowed to flow through the hose for a few minutes after it is full.

A funnel properly used would help where the hose is filled by hand, from a receptacle.

219. Removing air bubbles from the hose-level. — However filled, there is a possibility of the presence of bubbles of air at various points in the hose, and for the purpose of removing them a scheme something like the following should be employed :

Lower one end of the hose till the water begins to overflow the tube. Place the thumb firmly over the end of the tube and lower to the ground. Having first suspended the other end of the hose at a height of 5 or 6 feet, have a second party place his hand under the hose

6 feet from the end held to the ground, lift the hose to the height of 5 feet above the ground, hold it in that position for fifteen seconds, and then, holding the hand shoulder high, move it very slowly under the hose to the farther end. Any bubbles of air which may have been held by the water in the hose should follow the upper bend in the hose produced by the hand passing under it, and should be liberated through the tube at the farther end. The end near the ground may be lifted any time after enough hose has passed so that some portion shall touch the ground between the end and the hand moving the air bubbles. It is well to keep the thumb held tightly over the end of the tube until the hand reaches the farther end. Exercise care not to remove the thumb until the tubes are brought to the same height. Water will probably have to be added now to bring up the water in the tubes. If added slowly, no air need be introduced below the tubes.

220. Checking up the instrument. — After introducing the water and removing any air present, the two ends of the apparatus should be brought together, side by side, against some vertical surface upon which is drawn a horizontal line or which may have a horizontal upper edge, approximately shoulder high. Raise or lower one of the ends until the top of the water column stands even with the line or edge. The column at the other end should also stand even with the line or straight edge. Repeat the test after disturbing the main portion of the hose by lifting it at different points or partly or wholly stretching out a part or all of it. If the columns stand at the same height in each of three trials, it may be put into use at once.

If in any trial the columns fail to stand at the same height, this indicates the presence of air in the hose; the

hose should be then manipulated as suggested above until the air is removed, as indicated by the heights of the columns in checking.

221. Leveling rods. — In determining elevations with the hose-level, two rods are needed, one approximately 4 feet long and the other 3 feet longer, and both of 1-inch \times 1 $\frac{1}{4}$ -inch material. (See Figs. 71 and 72.)

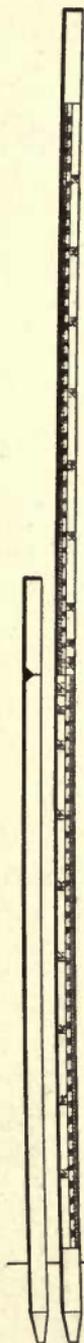
Observe (1) that only the long rod bears a scale; (2) that both rods have a zero mark at the height of 3 $\frac{1}{2}$ feet (42 inches); and (3) that the long rod has a double scale — one numbering down from the zero mark and one numbering up from the zero mark.¹

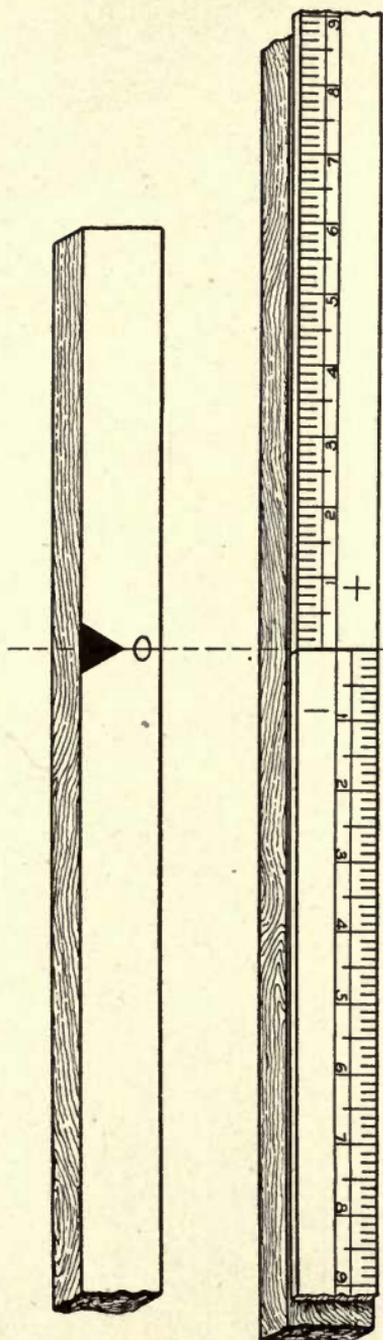
222. Construction of rods. — At present, these rods cannot be bought on the market and must, therefore, be home made. For scales, it is convenient to use yardsticks, and in the first attempts made in using this method of leveling, the cheap yardstick, so common for advertising purposes, was used. In constructing these rods, the following simple directions should be observed:

1. Have the rods straight and their lower ends square;

¹ The zero mark may be located at any height, but must be at the same height on both rods.

FIG. 71. — Leveling rods used with the hose-level. The short rod bears the zero mark only.





2. Be careful to have the zero at the same height on both rods (see Fig. 72);

3. Have the two scales on the long rod meet at the zero mark, and the edge of one scale in line with the similar edge of the other.

223. System of reading.

— It is not easy to buy rules or scales graduated to tenths and hundredths of feet, and while these can be procured, they are expensive. Most persons prefer to use scales graduated to inches, quarters, eighths, and sixteenths. Indeed, some of the standard leveling rods are so graduated. The decimal graduations are easiest handled after one becomes acquainted with them. For the convenience of persons desiring to use the hose-level with decimal reading, Table XVII has been prepared. By reference to the table, any reading in inches, eighths, and sixteenths can

FIG. 72. — Detailed drawing of Fig. 71.

TABLE XVIII

READINGS IN INCHES, EIGHTHS, AND SIXTEENTHS TRANSPOSED
TO DECIMALS OF A FOOT (HOSE-LEVEL)

INCHES- EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT
$\frac{1}{2}$	.0052	$3\frac{1}{2}$	.2552	$6\frac{1}{2}$	.5052	$9\frac{1}{2}$	.7552
0-1	.0104	3-1	.2604	6-1	.5104	9-1	.7604
$\frac{1}{2}$	.0156	$\frac{1}{2}$	.2656		.5156		.7656
2	.0208	2	.2708	2	.5208	2	.7708
$\frac{1}{2}$	.0260		.2760		.5260		.7760
3	.0312	3	.2812	3	.5312	3	.7812
$\frac{1}{2}$	.0364		.2864		.5364		.7864
4	.0417	4	.2917	4	.5417	4	.7917
$\frac{1}{2}$	.0469		.2969		.5469		.7969
5	.0521	5	.3021	5	.5521	5	.8021
$\frac{1}{2}$	.0573		.3073		.5573		.8073
6	.0625	6	.3125	6	.5625	6	.8125
$\frac{1}{2}$	.0677		.3177		.5677		.8177
7	.0729	7	.3230	7	.5729	7	.8230
$\frac{1}{2}$	.0781		.3282		.5781		.8282
1-0	.0833	4-0	.3333	7-0	.5833	10-0	.8333
$\frac{1}{2}$	.0885		.3385		.5885		.8385
1-1	.0937	4-1	.3437	7-1	.5937	10-1	.8437
$\frac{1}{2}$	.0989		.3489		.5989		.8489
2	.1041	2	.3542	2	.6041	2	.8542
$\frac{1}{2}$	.1093		.3594		.6093		.8594
3	.1146	3	.3646	3	.6146	3	.8646
$\frac{1}{2}$	.1198		.3698		.6198		.8698
4	.1250	4	.3750	4	.6250	4	.8750
$\frac{1}{2}$	.1302		.3802		.6302		.8802
5	.1354	5	.3854	5	.6354	5	.8854
$\frac{1}{2}$	.1406		.3906		.6406		.8906
6	.1458	6	.3958	6	.6458	6	.8958
$\frac{1}{2}$	.1510		.4010		.6510		.9010
7	.1562	7	.4062	7	.6562	7	.9062

READINGS IN INCHES, EIGHTHS, AND SIXTEENTHS TRANSPOSED
 TO DECIMALS OF A FOOT (HOSE-LEVEL) — *Continued*

INCHES EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT	INCHES EIGHTHS	DECIMAL OF FOOT
$\frac{1}{2}$	.1614		.4114		.6614		.9114
2-0	.1666	5-0	.4166	8-0	.6666	11-0	.9166
$\frac{1}{2}$	.1718		.4218		.6718		.9218
2-1	.1771	5-1	.4270	8-1	.6771	11-1	.9270
$\frac{1}{2}$	.1823		.4322		.6823		.9322
2	.1875	2	.4375	2	.6875	2	.9375
$\frac{1}{2}$	.1927		.4427		.6927		.9427
3	.1979	3	.4479	3	.6979	3	.9479
$\frac{1}{2}$	.2031		.4531		.7031		.9531
4	.2083	4	.4583	4	.7083	4	.9583
$\frac{1}{2}$	.2135		.4635		.7135		.9635
5	.2187	5	.4687	5	.7187	5	.9687
$\frac{1}{2}$	.2239		.4739		.7239		.9739
6	.2292	6	.4792	6	.7292	6	.9792
$\frac{1}{2}$	.2344		.4844		.7344		.9844
7	.2396	7	.4896	7	.7396	7	.9896
$\frac{1}{2}$	.2448		.4948		.7448		.9948
3-0	.2500	6-0	.5000	9-0	.7500	12-0	1.0000

be readily transformed to tenths and hundredths of feet.

224. To use the apparatus. — The way in which the hose-level is used is illustrated in Figs. 73 and 74. It is desirable to start the leveling from a stake whose elevation is known or assumed, as is the custom with the ordinary drainage level. The leveling proceeds as follows:

(a) The attendant, whom we will call the short-rod man, moves with the short rod and one end of the hose-level to stake 2. (In moving, he should be careful to hold a thumb firmly over the end of the tube.) He places the short

rod upon grade stake 2 and carefully holding it in a perpendicular position, brings the tube against the side of the rod, and raises or lowers the tube until the top of the water column comes to rest even with, or at the zero mark.

(b) At the same time the other party, whom we will call the long-rod man, places the long rod upon grade

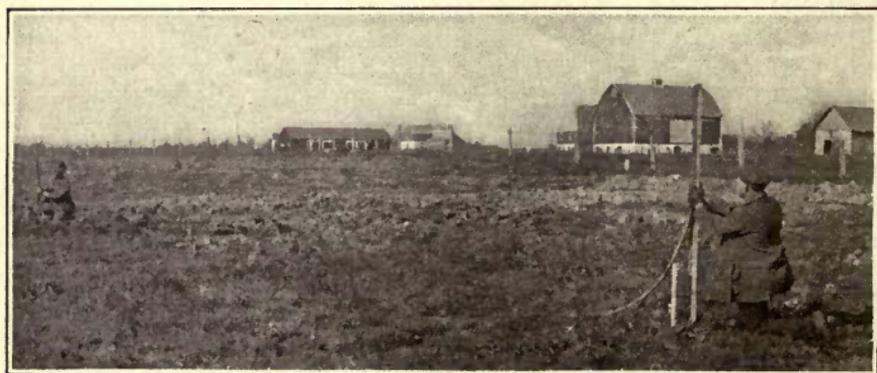


FIG. 73. — Hose-level in use.

stake 1, holds it carefully in a perpendicular position, and brings the tube of his end of the level against the scale side of the rod and, if necessary, raises or lowers the tube to permit the short-rod man to bring the column at his end to the zero. (See and study Fig. 70.) The short-rod end should be held so that the bottom of the curve (meniscus) of end of the water column stands even with the zero line.

225. How to read height of column. — When the short-rod man indicates that the water column at his end is at zero, the long-rod man should read the height of the water column, as indicated by the bottom of the curve (meniscus). This reading is used to determine the height of stake 2.

226. The reading. — When the top of the water column stands at zero on the short rod :

(a) If the top of the water column stands at zero on the long rod, the stakes stand at the same height above datum, and the reading is zero.

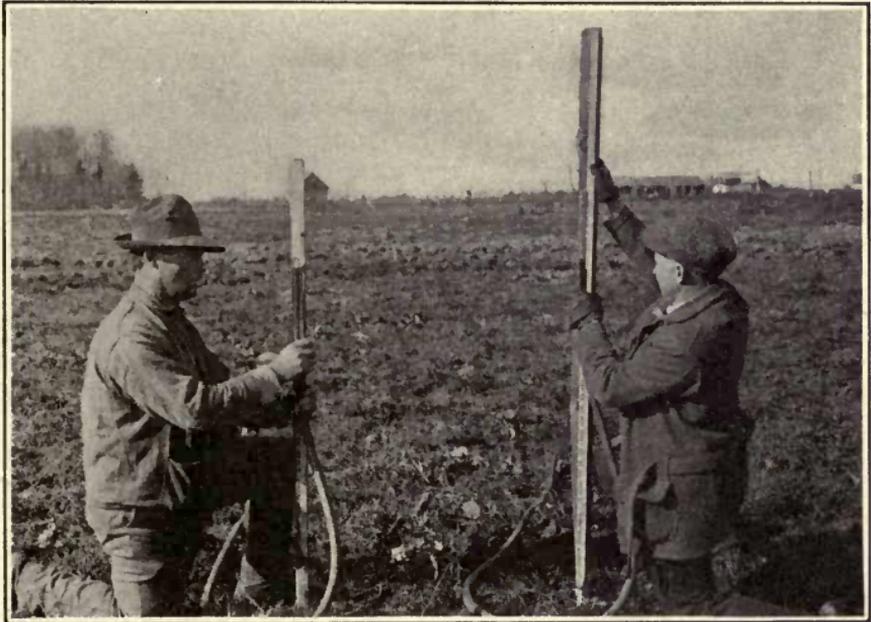


FIG. 74. — Nearer view of the hose-level in use.

(b) If the top of the water column stands above zero on the long rod, it is because stake 2 stands higher above datum than stake 1, and the reading is a positive reading.

(c) If the top of the water column stands below zero on the long rod, it is because stake 2 does not stand so high above datum as stake 1 (is lower than stake 1) and the reading is a negative one.

227. Moving. — After the reading has been made and properly recorded, the short-rod man, grasping his end of the level, moves to stake 3 and places the short rod

on grade stake 3, while the long-rod man moves to stake 2 and places the long rod upon stake 2. A reading is obtained in the same manner as before and properly recorded. This reading is used to determine the height of stake 3.

228. Recording data. — The table used for recording these readings will be somewhat different in form from Table XII. Table XIX illustrates the form to be used. In columns 3 and 4, of Table XIX, will be found the readings as they would have been obtained if the hose-level had been used in leveling for the drain shown in Fig. 47, and if a rod with decimal scale had been used. In all other respects Table XIX is like Tables XIII and XVI.

TABLE XIX

STAKE	DIS- TANCE	LEVEL READINGS		ELEVA- TION	FALL	ELEVA- TION OF BOTTOM OF DITCH	DEPTH OF DITCH	HEIGHT OF GRADE BAR
		(+) Above	(-) Below					
1	0			10.00				
2	50	.50						
3	100		.17					
4	150	1.92						
5	200	.70						
6	250		.45					
7	300		1.26					
8	350	.61						
9	400	2.45						
10	450	1.10						
11	500		1.20					

229. Positive readings. — A positive reading indicates that the stake for which it was taken (the stake upon which the short rod rested) is higher than the stake from which it was taken (the stake upon which the long rod rested), or that the stake upon which the short rod stood

for the reading is higher than the one on which the long rod stood. It should be introduced into the column in the table for positive readings, and after the number of the stake for which it was taken.

230. Negative readings. — A negative reading indicates that the stake for which it was taken is lower than the stake from which it was taken. It should be introduced into the column for negative readings in the table and after the number of the stake for which it was taken, — the stake upon which the short rod stood.

231. Computing elevations. — Computing the elevations of the several grade stakes becomes a very simple matter with the readings obtained by the hose-level. The reading for any stake indicates how much higher or lower it is than the stake from which the reading was taken. There is no height of instrument to determine or to work from.

In Table XIX the level reading for stake 2 is positive .50 foot. This reading was taken from stake 1, and the fact that it is a positive reading indicates that stake 2 is .50 foot higher than stake 1. Adding this reading to the elevation of stake 1 gives 10.50 feet as the elevation of stake 2. The reading for stake 3 is negative .17 foot, and the fact that it is a negative reading indicates that stake 3 is .17 foot lower than stake 2, from which the reading for stake 3 was taken. Subtracting this reading, .17 foot, from the elevation of stake 2 gives 10.33 feet.

232. The rule is apparent. — To determine the elevation of a stake, add its reading, if positive, to or subtract its reading, if negative, from the elevation of the stake from which its reading was taken.

When the elevations have been correctly computed from the readings in Table XIX, they are found to corre-

spond with the elevations as determined from the readings for the same drain in Table XV.

233. Recording reading taken, in feet and inches. — When scales graduated to feet, inches, quarters, eighths, and sixteenths are used, the writer has found it most satisfactory to read and record all fractions of the inches in terms of eighths only. For example :

$$\begin{aligned} \frac{1}{16} \text{ inch} &= \frac{1}{2} \text{ eighth inch.} \\ \frac{1}{4} \text{ inch} &= 2 \text{ eighths inch.} \\ \frac{1}{2} \text{ inch} &= 4 \text{ eighths inch.} \\ \frac{7}{16} \text{ inch} &= 3\frac{1}{2} \text{ eighths inch.} \\ \frac{13}{16} \text{ inch} &= 6\frac{1}{2} \text{ eighths inch.} \end{aligned}$$

Three feet $7\frac{13}{16}$ inches are recorded in the table as 3-7-6 $\frac{1}{2}$.

In practice, one quickly becomes used to this plan of expressing values and recording them, and finds little difficulty in using them in making his computations.

Table XX is a reproduction of level readings as they appear in notes for two drains 300 feet and 250 feet in length, respectively. Note in columns 3 and 4 the relative positions in the column of (1) the figures expressing feet, (2) those expressing inches, and (3) those expressing the fractions of an inch (always expressed in eighths of an inch).

234. Relation of values. — An eighth of an inch is a trifle more than one one-hundredth of a foot (.0104). A sixteenth of an inch is a little more than five thousandths of a foot (.0052). When one works as close as one-sixteenth of an inch, in ordinary drain work, one is doing well, and this is closer than can be done with the ordinary cheap drainage level. One can, with care, work to one-sixteenth of an inch with the hose-level.

TABLE XX

LATERAL FROM STAKE 4 OF MAIN

STAKE	DISTANCE	READINGS		ELEVATION OF STAKES	GRADE	ELEVATION OF BOTTOM OF DITCH	DEPTH OF DITCH	HEIGHT OF BAR
		(+) Above Ft. in. $\frac{1}{4}$'s	(-) Below Ft. in. $\frac{1}{4}$'s					
1	0			12-5-1				
2	50	- 1-2 $\frac{1}{2}$						
3	100		- 2-0					
4	150	3-6 $\frac{1}{2}$						
5	200	1-0						
6	250	7-0						
7	200		- 3-6 $\frac{1}{2}$					

LATERAL FROM STAKE 5 OF MAIN

1	0			12-9- $\frac{1}{2}$				
2	50	- 4-						
3	100	- 11-3 $\frac{1}{2}$						
4	150	1-0-1 $\frac{1}{2}$						
5	200	1-1-6 $\frac{1}{2}$						
6	250	- 9-7 $\frac{1}{2}$						

CHAPTER X

USING THE HOSE-LEVEL WITHOUT LEVELING RODS

FOR drains of moderate length, when the surface of the land is fairly regular, and when the fall does not exceed three feet for the whole line, a very simple procedure may be followed. Figure 75 represents the profile of a piece of field in which a 400-foot lateral is to be laid. The lateral must be 40 inches (3 feet 4 inches) deep at the main. The grade stakes are in place (50 feet apart) as shown in the figure. Stake 1 was a grade stake of the main and the depth of the main at that stake has determined the depth of the lateral at that point.

235. Long stakes. — Two inches back from each grade stake, there must be driven firmly into the ground one of the stakes that will later be needed to carry the grade bar (or “batter board” as it is sometimes called). This stake should be 1×4 inches, and after driving, should stand out of the ground 3 to 5 or more feet, depending upon its location in the line and the fall of the land and of the drain. Each stake must be as high as the level of the grade bar at the head of the drain will stand. When in place, it should be perpendicular and its face should stand at right angles to the line of the drain. These stakes are shown in Fig. 76.

236. To establish datum plane. — The depth of the drain at its upper end should now be determined. That

depth subtracted from 5 feet 6 inches¹ gives the height of the top of the grade bar above the grade stake. Let us suppose that in this case the depth of the drain is to be 3 feet; 3 feet subtracted from 5 feet 6 inches gives 2 feet 6 inches as the height of the bar above grade stake. On the inner edge of the long stake, by pencil, chisel, or some other mark, the height of the grade bar is indicated (2 feet 6 inches in this case).

237. Leveling. — With the hose-level, the leveling begins at the end stake (stake 9 in this case). In this case the leveling proceeds down instead of up the drain. The hose-level is stretched between stakes 9 and 8 and the tubes of the level are placed one against the tall stake 9 and one against tall stake 8. The tube at 9 is brought into position so that the top of its water column stands even with the mark on the edge of the stake indicating the proper height of the grade bar. The man at stake 8 now carefully marks on the edge of stake 8 the height of water column in the tube at his end of the level. The level is now placed between stakes 8 and 7, and the tubes brought against the edges of the stakes; the tube against the edge of 8 is brought into position so that the top



Fig. 75. — Profile of field to be drained.

¹ In the computations for this drain, feet, inches, and fraction of the inch will be used.

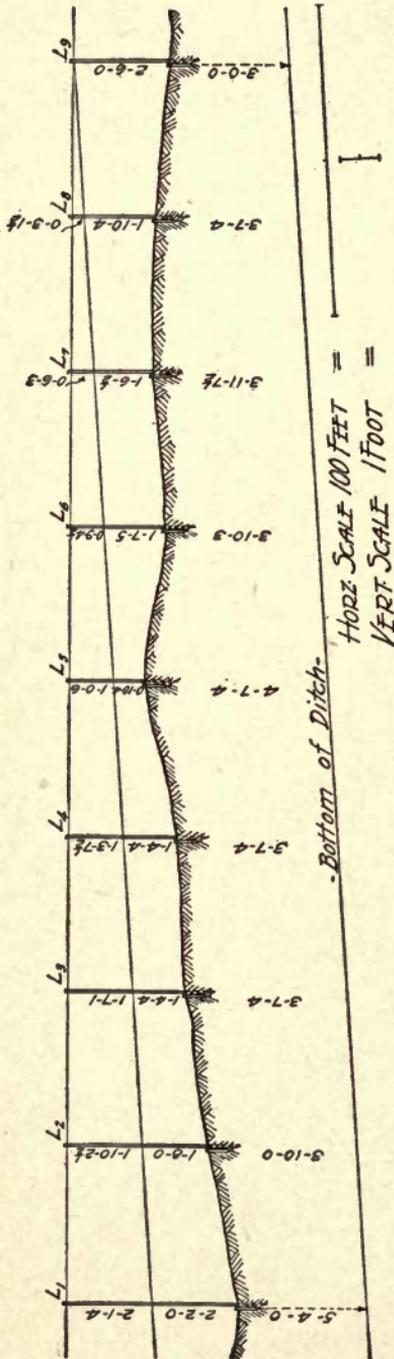


FIG. 76. — Same as Fig. 75 with the tall stakes in position. The line L_9 is in reality a datum plane, for from this plane all computations in establishing grade, depth of ditch, etc., are computed.

of its water column stands even with the mark just placed upon it. Then the man at stake 7 carefully marks on the inner edge of stake 7 the height of the top of the water column. In like manner the height of the mark on stake 7 is indicated on stake 6, and that on stake 6 is indicated on stake 5, and so on till a similar mark is placed upon stake 1. It is not necessary to explain that all of the marks so placed on the inner edges of the stakes are in the same horizontal plane and on the same level. This plane is a datum plane and from it we make our actual computations.

238. The height of grade bars. — The height at which the grade bar should stand at stake 1 is now determined and marked

on the inner edge of stake 1. In this case the depth of the ditch at stake 1 is to be 40 inches as previously stated. Forty inches equals 3 feet 4 inches, and this subtracted from 5 feet 6 inches gives us 2 feet 2 inches, and this height above grade stake is now marked on the inner edge of the long stake at 1, as it was on stake 9.

239. To determine fall by hose-level. — Referring now to Fig. 76, if we draw a straight line connecting points L_9 and L_1 , this line passes through all the other level marks on the several other stakes. It is level. If we connect the point L_9 , which is also the height of the grade bar on stake 9, with the point B_1 , which is the height of the grade bar on stake 1, with a straight line, that line represents the fall of the drain from stake 9 to stake 1. (It shows the location of the boning line.)

240. Computations. — The distance from the point L_1 to the point B_1 represents the actual fall or drop of the drain between stake 9 and stake 1. This measuring may be done with an ordinary rule or yardstick. In this case the distance from L_1 to B_1 is found to be 2 feet $1\frac{1}{2}$ inches, or 2-1-4. This is the total fall whether it is regular or broken.

The length of drain is 400 feet, divided by the grade stakes into eight 50-foot intervals or sections. If the fall is constant and the total fall from stake 9 to stake 1 is 2 feet $1\frac{4}{8}$ inches, the fall from stake 9 to stake 8 — indeed the fall from any stake to the stake next below it — is one eighth of 2 feet $1\frac{4}{8}$ inches. Dividing, we find that fall to be 3 inches and $1\frac{1}{2}$ eighths $(2-1-4) \div 8 = (0-3-1\frac{1}{2})$. At stake 8, then, the grade bar will stand 3 inches and $1\frac{1}{2}$ eighths below the level mark. At stake 7 the grade bar will stand twice 3 inches and $1\frac{1}{2}$ eighths below the level mark; at stake 6 the grade bar will stand three times 3

inches and $1\frac{1}{2}$ eighths below the level mark, and so on down to stake 1.

TABLE XXI

STAKE	DISTANCE	FALL FOR 50 FT.	DISTANCE OF GRADE BAR BELOW LEVEL	HEIGHT OF GRADE BAR (ABOVE GRADE STAKE)	DEPTH OF DITCH
1	0	$0-3-1\frac{1}{2}$	2-1-4	2-2-0	3-4-0
2	50		1-10-2 $\frac{1}{2}$	1-8-0	3-10-0
3	100		1-7-1	1-4-4	4-1-4
4	150		1-3-7 $\frac{1}{2}$	1-4-4	4-1-4
5	200		1-0-6	-10-4	4-7-4
6	250		0-9-4 $\frac{1}{2}$	1-7-5	3-10-3
7	300		0-6-3	1-6- $\frac{1}{2}$	3-11-7 $\frac{1}{2}$
8	350		0-3-1 $\frac{1}{2}$	1-10-4	3-7-4
9	400		0-0-0	2-6-0	3-0-0

241. Placing the marks for grade bars. — A permanent mark (with pencil, chisel, or knife) should be made on the inner edge of each stake to indicate the proper height of grade bar. And this height is obtained for any stake by carefully measuring down from the datum plane on that stake, with a rule or yardstick, the distance indicated for that stake in column 4 of the table.

242. Checking up on depth of ditch. — Before putting up the grade bars, it will be well to check up on the depths of the ditch at a few points along the line, and, if the ground is rather irregular, at all points. It may be that a constant grade, or fall, from stake 9 to stake 1 may call for too great a depth of ditch at some point, or too shallow a depth at some other. The bottom of the finished ditch stands 5 feet 6 inches below the boning line. With a rule or yardstick, determine the distance at stake 2 from

the grade bar mark to the grade stake, and record in column 5 of your notes. Then pass to stake 3 and determine distance from grade bar mark to grade stake, and so on to stake 8. In the case in hand, these measurements, if correctly made, would appear in the notes as in column 5 of Table XXI.

243. Breaking the grade.—The depth of ditch at any point is found by subtracting the height of the grade bar from 5 feet 6 inches. The depths as shown in column 5 of Table XXI range as great as 4 feet $1\frac{1}{2}$ inches. This is not objectionable except for the extra expense in digging. Raising the grade bar 4 inches at stake 5 would mean a break at that point in the grade or fall of the drain, but would still leave a good fall for the upper half of the drain. Such a change would require another set of computations. But such computations are simple.¹ It would require also that a new set of marks be established for the grade bars.

244. Placing the grade bars.—With the grade or fall definitely established, the computations completed and the proper heights for the grade bars marked on the inner edges of the stakes, the grade bars should be placed. At each stake, and three to four feet from it, on the opposite side of the proposed ditch, should be driven a second stake of proper height. The grade bar, in each case straight edge up with a spirit level resting upon it, should be brought into position against the front side of the stakes so that, when level, the upper edge rests even with the mark previously put upon the inner edge of the first

¹ If the mark B_5 at 5 were raised 4 inches, the distance from L_5 to B_5 would then be (0-8-6) and this would represent the fall from B_9 to B_5 . The fall from B_5 to B_1 would be (2-1-4) less (0-8-6) = (1-4-6). $(0-8-6) \div 4 = (0-2-1\frac{1}{2})$, the fall per 50 feet between stake 9 and stake 5, while $(1-4-6) \div 4 = (0-4-1\frac{1}{2})$, the fall per 50 feet between stake 5 and stake 1.

long stake to mark the proper height of bar at that stake. In this position the bar should be nailed to the two stakes.

245. Checking the bars. — After the bars are in place, one should sight over them to see that their tops are in line. The drainage work proceeds from this point in the ordinary way, except that in opening the ditch its edge should not be cut nearer than one foot to the tall stakes.

246. Grade stakes and finders not needed. — As is readily seen, in using such a scheme as that above described, the grade stake is of little service, and may be dispensed with. When the grade stake is dispensed with, care should be exercised to have the long stakes stand in fair alignment, and one foot back from where it is desired to have the edge of the ditch. The finder is also unnecessary. Any data may be recorded on the long stake.

247. For more extensive work. — For drains of considerable length, and on lands of considerable roughness of contour, the leveling may be done with the hose-level, without rods, but some modifications must be introduced. Under such conditions, it might be necessary to divide the drain into sections and to level for each section separately. The fall (in surface) for each section might be determined separately. This would most likely result in a break in grade between sections, and it would be necessary to observe the precautions previously indicated regarding the use of silt basins at breaks in grade. It is entirely practical, however, to level and find the fall for each section separately, and to combine the falls and establish a constant grade for the entire drain or to establish breaks in grade at other than section points—to conform grade to the contour of the line of the drain, as in any other case. In establishing grade, proper corrections must be made in passing from one section to another.

CHAPTER XI

DRAINAGE INDICATIONS

It seems desirable to set forth, specifically, a few of the more important situations that indicate when drainage is necessary. It often occurs that conditions exist which produce effects in the way of crop failure, unsatisfactory soil conditions, and the like; and the farmer is unable to comprehend the cause, or if so, he still fails to determine upon the remedy and to apply it. The following paragraphs will set forth, briefly, some of these conditions.

248. Low flat areas of light soil.—Probably the commonest case is that of rather flat, low-lying areas, where surface water does not lie long upon the ground. It runs away largely as surface drainage or sinks quickly into the ground. Because of this rapid disappearance, and the absence of small long-standing pools upon the surface of the ground, it is assumed that the land is well drained. An examination, however, with spade or auger may show that the water-table stands within two feet, and often within a few inches of the surface of the land.

It is not unusual to find areas of this sort with surface soil a sand or sandy loam, which helps to mislead one as to the real causes of misbehavior of the land. Recently an appeal came from a farmer to the soils department of an agricultural college, setting forth the peculiar behavior of a field, and asking for advice as to methods of soil management to be employed and the brand of fertilizer that

should be used. A representative of the college visited the farm. He found that the crop (corn) growing upon the field was very pale and lacking in vigor. The symptoms all indicated a wet soil. The owner was sure the land was naturally well drained. An examination revealed the fact that in many places the water-table stood within a foot of the surface.

The difficulty in these cases is due to the presence of an underlying impervious layer of subsoil. It is most frequently a stratum of clay. It is sometimes a layer of

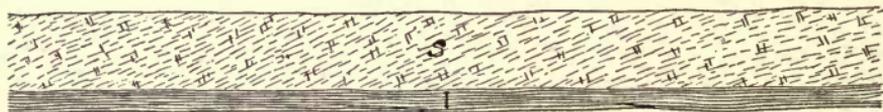


FIG. 77. — To illustrate the conditions described in paragraph 248. *S* represents soil, which may range from a few inches to several feet in thickness. *I*, impervious or semi-pervious layer. It may be clay, hard-pan, or rock, which may range from a few inches to many feet in thickness. It usually occupies horizontal position.

sand-iron hard-pan. Sometimes it lies within two or three feet of the surface. If within three feet, it is usually desirable to set the tile down in this subsoil sufficiently to give to the drain a total depth of at least three feet. (See Fig. 77.)

249. Considerable slopes of light soil. — In Fig. 78 is illustrated an interesting case. The soil occupies an irregular slope and is a rich sandy loam underlaid, as shown, by a sandy hard-pan. The hard-pan permitted only slight movements of water downward, and while the soil was a sandy loam and, therefore, fairly open, it did not permit a sufficiently rapid movement of soil water laterally to provide the necessary drainage. The result was that while the field appeared to have excellent natural

drainage, and while the soil was apparently of excellent quality, it actually was very unproductive because of the over-wet condition of the soil.

250. Extended flat or even moderately rolling areas of heavy soils. — On these areas, after a rain or during and

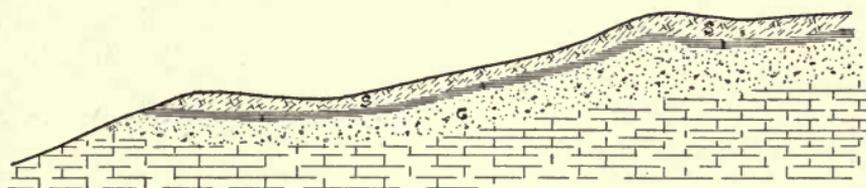


FIG. 78. — To illustrate the condition existing in a field drained in October, 1914. *S*, the soil ranged from 18 inches to 36 inches in depth. *I*, a sandy hard-pan averaging 6 inches thick, and underlaid by a coarser sandy soil, which in turn extends down to the underlying lime stone. Several areas in the field were very wet before the field was drained.

after spring thaws, the water stands on the flat parts or in the surface depressions. Frequently the higher parts of rolling fields may be ready for the harrow or plow, but work is deferred because of the wetness of the low places or depressions. Not infrequently the beginning of field

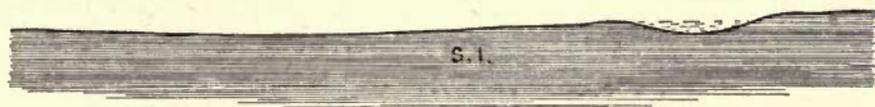


FIG. 79. — The condition described in paragraph 250. The soil *S.I* is a heavy clay, which allows but slow movement of water through it.

operations is thus so greatly delayed that under the action of sun and winds, the soil of much of the higher parts of the field becomes over-dry before it can be (or is) subjected to harrow or plow, and may even thus become unfitted to receive the seeding which follows.

This undesirable moisture condition is due to the heavy or impervious nature of soil and usually the immediate

subsoil. Proper drainage produces a more pervious condition of both soil and subsoil, which eventually, usually shortly, results in the immediate removal of all surplus water (Fig. 79).

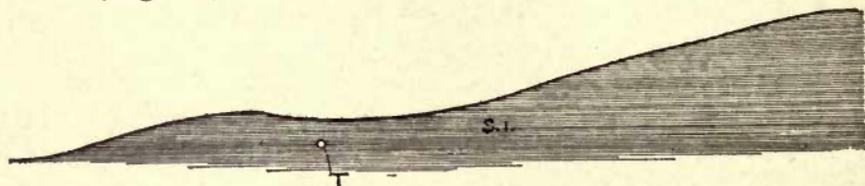


FIG. 80. — To illustrate the first conditions described in paragraph 251. *S.I.*, a clay soil. If the area be not too wide, a tile laid at *T*, the center of the area and at right angles to the slope, will remove the water.

251. Limited flat or depressed areas on slopes. — Two cases are illustrated by Figs. 80 and 81. In the first the soil is a heavy clay or till. In the second example the soil, a sand or loam, is underlaid by a heavy clay or till, which, partly because of its imperviousness, and

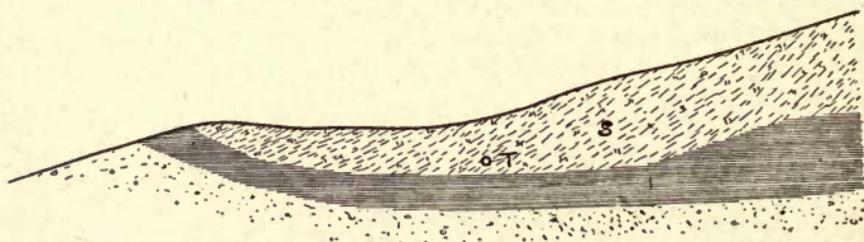


FIG. 81. — To illustrate the second condition mentioned in paragraph 251. *S* is an ordinary soil underlaid by *I*, an impervious or semi-pervious layer. The actual condition might vary considerably from that shown in the cut, but the general results would be the same. If the area be not too wide, a tile laid at *T*, under the foot of the upper slope and at right angles to it, will take care of the water.

partly because of its saucer-like shape, holds the water, and thus renders the soil above unproductive. In the first case, the water is held upon the surface until it has slowly disappeared, partly down through the soil, and partly by evaporation. In the second case, the water is

held below the surface until it is removed by the same processes. In both cases, injury is worked to both soil and crop.

252. Limited flat or depressed areas on hilltops. — The soil conditions in this case do not differ from the last

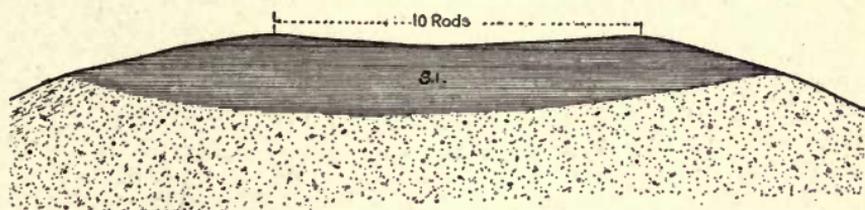


FIG. 82. — To show how a heavy clay soil, surmounting a hill top, as described in paragraph 252, might retain a large amount of water and require draining.

named except in position. (See Figs. 82 and 83.) A case of this class is mentioned in a previous paragraph. An area of this kind amounting to a half acre was so wet that it could not be spring-plowed in time for a crop.

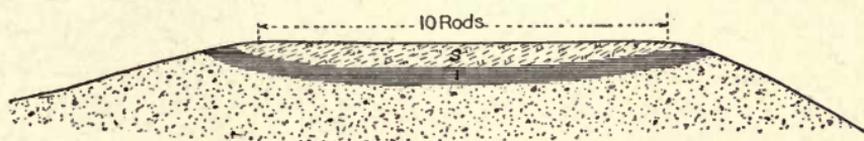


FIG. 83. — To show another condition that would result in the over-wet hill top mentioned in paragraph 252. *S*, any fairly open to open soil. *I*, an impervious or semi-pervious layer ranging from a few inches to several feet in thickness. It may be underlaid by a very open soil.

Later in the season a simple system of tile was laid with its outlet 50 yards down the slope, and close to the line fence. After a few years the outlet was connected to a near-by lateral of another tile system. No trouble has been experienced from wet ground on the hill top since the system was installed.

253. Springy low flat areas. — The springs in low flat areas occur because the underground water, moving from other higher areas, cannot escape downward sufficiently rapidly because of underlying clay, hard-pan, or rock.

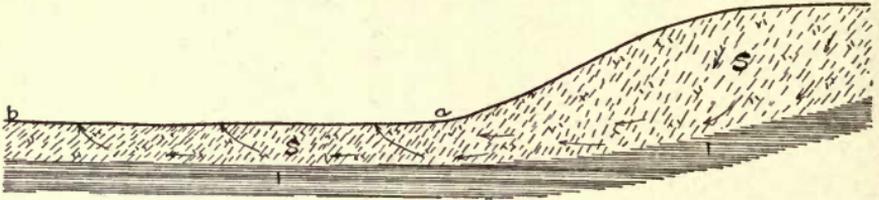


FIG. 84. — To show how a springy condition might be produced. The clay or hard-pan *I* would divert the water sinking through the soil *S*, and cause it to saturate and rise through the low lying soil (*ab*). See paragraph 253.

The water, therefore, comes to the surface as springs. (See Fig. 84.) Sometimes this underground water approaches between two impervious layers as is illustrated in Fig. 85. Such a condition as this was discovered to

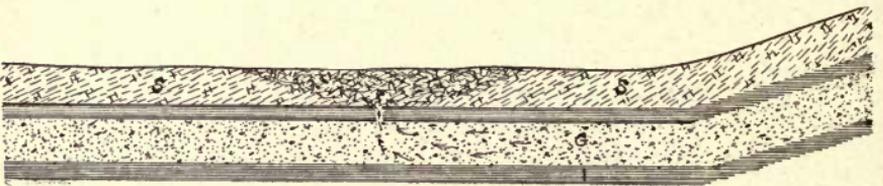


FIG. 85. — To illustrate the second condition mentioned in paragraph 253. *S*, any fairly open soil. *I, I*, clay or hard-pan. *G*, a sand or gravel layer filled with water gathered at some higher point. This water is under pressure, and, therefore, rises through any opening that may occur in the upper layer of clay or hard-pan.

exist over an extended area in England, and led to a very interesting and successful line of tile drainage in that country as early as the year 1764.

A line or system of tile, properly placed, intercepts and carries off the water which otherwise would rise to the surface and keep the soil wet and cold. The amount of

tiling required will depend on the size of the area. If it were found that but one spring existed in the tract, an arrangement like that shown in Fig. 86 would remove the water. If there were several springs, a line or a system of tile might be required, depending upon the relative location of the springs and the nature of soil of the area and its size. If the condition were like that shown in Fig. 84, a single line of tile, laid at proper depth, and along the base of the slope (under *a*), and at right angles to it would intercept and carry off the water.

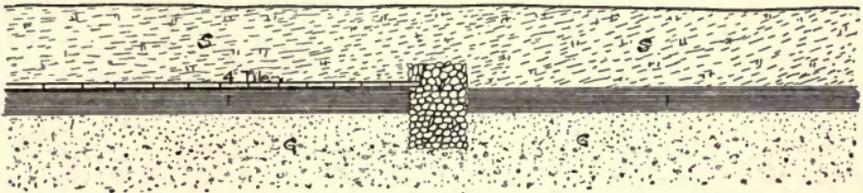


FIG. 86. — To show how the well, mentioned in paragraph 253, two feet in diameter, may be sunk, and filled with stone to permit the ready passage of the water of a spring to the drain tile and so increase the efficiency of the tile. The dimensions shown in the figure must of course vary with conditions. The size of tile required will vary with the size of the spring.

254. Springy areas upon slopes. — A springy area well up on a considerable slope is a rather common thing, especially in the drift soils. Sometimes the area is small; sometimes it includes several acres. The presence of the springs is due to conditions similar to those producing springs on the low areas. The situation and the facts are presented only to show that the causes and the remedy are the same, and as simple as in the previous case. (See Fig. 87.) In limestone formations, a condition occurs which is illustrated by Fig. 88, taken from Fippin, Cornell Reading Course. It is self-explanatory.

255. Muck or swamp areas. — The muck soils vary greatly in depth, the range being from a few inches to

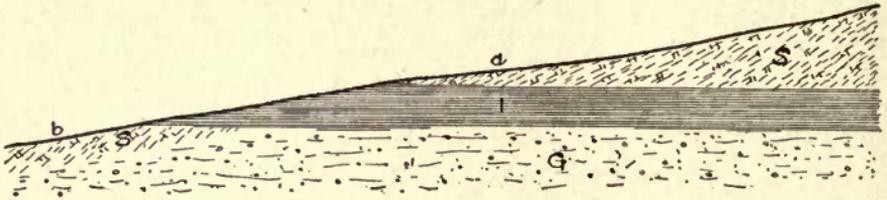


FIG. 87. — To show how springs may occur on slopes, as mentioned in paragraph 254. Water sinking through soil *S* is deflected by the layer of clay or hard-pan *I*, and caused to appear at the surface at *a*, and to saturate the surface as far at least as *b*.

many feet. When the area does not exceed forty to eighty acres, and when it lies adjacent to a fairly deep natural waterway or to a good open ditch, the drainage needs and

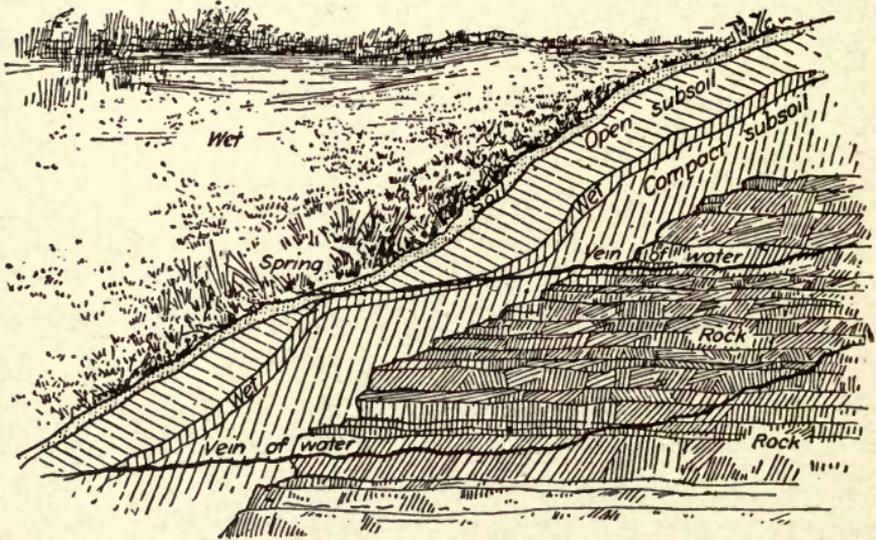


FIG. 88. — Sectional view of soil and rock formation, showing the underground movement of water and the position of resulting wet areas on the surface. In addition to the springy places, the soil is kept wet by the seepage of water along the top of the compact subsoil. This figure also illustrates the reason for locating a cross drain above the springy area in order to effect drainage. This method cuts off the water supply. (Fippin, Cornell Reading Course.)

operations are simple. The chief precaution is to set the tile at a good depth, remembering that muck soils lose greatly in volume when drained, with the result that after a few years the surface settles so near the tile that they may be endangered from frost and agricultural tools. The writer has been under the necessity of lowering a number of systems of tile in muck soils because of the shrinking of the mass and consequent settling of the surface.

256. Small muck areas without natural outlets. — It frequently happens, especially in the glacial drift areas, that one to several small muck areas occur on a single

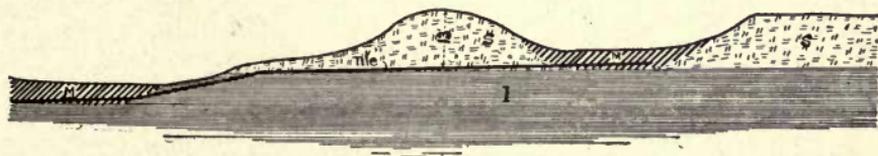


FIG. 89. — To illustrate the isolated muck areas mentioned in paragraph 256. The line of tile laid to drain the area is shown. *S*, soil; *M*, muck; *I*, underlying clay.

farm. They may range from one-fourth acre to five acres, entirely surrounded by higher land. When the surface of the muck area stands higher than an adjacent low area, as it often does, and when the horizontal distance between the two is not great, it may be drained by laying a line of tile through the high ground, separating it from the adjacent low area, to the low ground. This line may discharge into a line of tile in the lower area (see Fig. 89) or into a natural water way or open ditch.

When the surface of the area is so low that sufficient fall cannot be secured in draining to an adjacent area, or where the horizontal distance is great or the separating ridge is high, but one possible economical means of drain-

age is left — that by well. The feasibility of draining by well can be determined only by trial. (See paragraph 202.) Figure 89 shows a muck which was drained by tile drain. The area drained was about two acres. The depth of cut at *ab* was 13 feet. The price paid for digging 15 rods, laying the tile and filling of the cut was \$2 a rod. It was considered a good investment. In another instance \$1 a rod was paid for digging, laying tile, and filling 25 rods of outlet to 8 acres of muck swamp.

257. Shallow ponds resting upon muck beds. — In some cases these shallow ponds are permanent, occupying their beds the year through. In some cases their beds are dry a part of the year. The description of an experience in draining such a pond may be helpful. The pond in question had an area of perhaps two acres and was permanent. Its bed occupied a part of a 6-acre muck area. A shallow open ditch, extending 40 rods through an adjacent field, was dug to drain the water from its bed. Later the same open ditch was lowered and extended the length of the muck area, and at a maximum depth of 18 inches. It was discovered that the muck was very shallow and rested upon a heavy clay subsoil. The bottom of the 18-inch ditch rested in the clay subsoil at practically every point. After the open ditch had been in operation two years, the muck area was tiled, the main line of the tile occupying the line of the last mentioned open ditch through the muck area. The outlet was accomplished by a line of tile not following the original open drain in the adjoining field. The obtainable fall was so slight that the depth of the main tile drain in the muck area did not exceed three feet at any point, while at some points it did not exceed two feet. The tile drain has been in successful operation ever since its installation

six years ago. Figure 90 shows a profile section through the center of the pond bed.

258. Shallow ponds resting on other than muck beds.—The nature of the soil comprising the bed of the pond is not so material as whether there is sufficient natural fall to a water course or to an open ditch. Where the condition of fall and outlet are correct, the pond can usually be drained.

259. Shallow ponds not having sufficient fall or natural outlet.—Shallow ponds sometimes occur both upon muck beds and upon clay or loam beds, where conditions do not permit tile drainage. There may not be sufficient fall; the distance over which the drain must extend and the depth of digging required may be too great. In either case there remains the possibility of draining by well. (See paragraph 202.) A very interesting case of this kind is reported in Water Supply Paper 258, United States Geological Survey.

260. Low flat areas whose surfaces lie only slightly above that of an adjacent stream or lake, which cannot be lowered by drainage.—In 1894 the Wisconsin Experiment Station undertook an interesting experiment in draining a 10-acre area of muck



FIG. 90. — Diagram showing muck bed originally occupied by pond. The whole muck area referred to in paragraph 257 is now drained and producing excellent crops.

soil.¹ The area lay adjacent to a stream which emptied into Lake Mendota less than half a mile away. The stream could not, therefore, be lowered. The method of procedure was somewhat as follows :

1. The area to be drained was cut off from the bank of the stream by cutting a narrow trench, parallel to the stream and probably four feet deep (the depth is not given in the report). This trench was filled with clayey soil hauled from higher ground near by, so that when the earth was fully settled and the hauling completed, the top of the dike thus formed stood 18 inches above the surface of the stream. This artificial dike was to prevent the passage of water from the stream to the drained area either by seepage or overflow.

2. At one corner of the area, just in from the dike, a reservoir or sump, 40 feet by 60 feet and 4 feet deep, was dug. An open ditch dug parallel to the dike and ten feet from it opened into the reservoir. Later, tile drains were laid two rods apart, emptying into the opened ditch ; a few of them opened into the reservoir, so that the drainage water from the whole system gravitated to the reservoir. Between the reservoir and the dike a well 4 feet deep was dug, walled with brick, and connected with the reservoir by a line of 6-inch sewer tile. "Over the well was placed a fourteen foot eclipse windmill, carried on a forty-foot tower. The pump rod of the windmill was attached to an eight by twelve inch iron pump placed low down in the well." By this means the drainage water was lifted over the dike from the well. For several years the windmill, which was in gear all the time, removed the drainage water from the 10-acre area.

¹ Twelfth Annual Report Wisconsin Experiment Station, p. 232.

Arrangements were made for an extra pump, but it was seldom if ever used.

The drainage sytem has now been in operation twenty-one years. "The old windmill has worn out and we now have an electric motor to run the pump. About twenty acres on the west side of the creek has been added to the project and the water from it is brought into the old reservoir by an iron pipe under the creek. The tile run practically all of the time. A float on the water in the reservoir starts the motor as soon as the water is high enough to reach the bottom of the tile and it stops automatically as soon as the reservoir is empty. The system is a success in every way." — E. R. JONES.

261. Situations already referred to. — The laying of tile through quicksand, the removing of water directly from springs met with in draining boggy places, and the utilizing of special means to remove excessive accumulations of surface water to underground drains have been discussed in paragraphs 207, 208, and 209 respectively. While they have been treated as matters pertaining to construction, in another sense they are closely allied to the matters discussed in this chapter.

CHAPTER XII

DRAINAGE AND THE GROUND WATER SUPPLY

ALARM is expressed from time to time over what is looked upon as a diminishing ground water supply. Both open ditching and tile draining are charged with removing water which otherwise would wholly, or in part, sink into the lower soil to retain the ground water at normal condition.

262. The ground water-table is falling.— In many parts of the United States, it is a matter of common knowledge that for years springs have been drying up or diminishing in volume. Streams that once flowed in considerable volume have disappeared. In some cases they still flow for a short distance over their old beds and finally disappear below the surface. Wells that once furnished an abundant supply of water at 10 to 30 feet below the surface have failed in their supply, to be, in some cases, supplanted by other wells of twice their depth. These in turn have sometimes failed, and have given place to drilled wells of much greater depth. The depth of water of many of the deep-drilled wells is said to be decreasing. From data gathered upon nearly 29,000 wells located in forty-eight states, McGee¹ shows that in some regions there is a considerable fall in the ground water level, and that the fall is greater in dug than in drilled wells. From

¹ W J McGee, Bulletin 92, Bureau of Soils, "Wells and Subsoil Water."

the rather more complete data obtained on nearly 21,000 of these wells, the following conclusions are drawn :

46.2 per cent show change in water level ;

53.8 per cent show no change in water level.

A part of these were dug wells and a part were drilled wells.

Of the dug wells 53.6 per cent showed change ;

Of the drilled wells only 23.4 per cent showed change.

Of the dug wells, for the period covered by the data :

45.5 per cent showed a mean lowering of 4.31 feet ;

17.5 per cent showed a mean rise of 3.68 feet.

Of the drilled wells, for the period covered by the data :

21.25 per cent lowered to the mean amount of 12.83 feet ;

3.3 per cent gave a mean rise of 11.08 feet.

“The minimum lowering per decade for the entire country is but 0.677 for the dug wells, and over three times as much, or 2.167 feet for the drilled wells.”

263. Interesting facts concerning ground water-tables.

— Of the nearly 29,000 wells, over 61 per cent have their water-table within 30 feet of the surface, and only 5.7 per cent (1635 wells) have their water-table below 100 feet from the surface, and nearly one-fifth of these (307) are in one state.

264. Chief causes resulting in lowering of ground water. — Several causes are suggested as probably having a part in producing the lowering of ground water. The ones most commonly offered may be grouped as: (1) those resulting in increased losses by surface drainage — in increasing the run-off; (2) those resulting in increased losses by evaporation — increasing the fly-off; (3) the removal of natural surface reservoirs; and (4) a direct draft upon the waters themselves.

265. Increasing the run-off. — The removal of forests, the breaking of prairies, and careless cropping and indifferent tillage of lands after they are brought under cultivation all tend to increase the percentage of precipitation which fails to enter the ground, but instead runs off as surface drainage. Natural vegetation, whether forest or prairie, with the resulting earth covering, permits the excess of precipitation to move off so slowly that a very considerable portion of it enters the soil to become ground water — and thus to become “cut-off” water instead of “run-off” water. The absence of the forest and prairie conditions, and the compacted or puddled soil which is likely to result from bad soil management, increases the run-off and decreases the cut-off.¹

266. Increasing evaporation. — The removal of forest and prairie vegetation and the indifferent management of cultivated land undoubtedly result in great losses by surface evaporation. It may be questioned, however, whether the mere removal of forest and prairie vegetation need increase evaporation losses, if honest, intelligent soil management were followed. But it too often is not.

267. The removal of surface reservoirs. — It is contended by some that the draining of ponds and swamps by open ditch or tile drain removes water, much of which would eventually find its way, by gravity, to become a part of the great underground supply, and that as a part of this supply it would eventually become distributed to points quite remote from its original point of storage. This is probably correct, in part at least. It may very reasonably be questioned, however, whether this replenishment of the underground water supply would prove of

¹ For definition of cut-off, run-off, and fly-off, see F. K. Cameron, *The Soil Solution*, p. 22.

as great economic value to human kind as will the land thus reclaimed by drainage. Where the drainage of such areas is accomplished by means of wells, both contentions are satisfied.

Even ordinary tile drainage, practiced for the purpose of permitting soils to do reasonable service agriculturally, is regarded with suspicion by those who are jealous for the future safety of the nation — as depending upon future food and water supply.

268. Direct draft upon underground waters. — This draft is brought about: (a) in the draining of mines by pumps or tunnels; (b) in the action of artesian wells, especially where they are permitted to operate uncontrolled; and (c) in the procuring of a city's water supply by means of municipal wells. The draining of mines, the digging of artesian wells, and of city and other wells are all legitimate, and could hardly be forbidden by law. It would seem, however, that the reckless wastefulness, practiced in some of the artesian basins of our country, might be, and should be, restricted by law.

269. The interpretations placed on the fact of a falling ground water-table. — We are frequently startled by the appearance of an article in the public press,¹ or a public utterance prophesying a serious future condition because of a failing water supply. Such prophecies might be considered seriously if there were positive assurances that the past and present falling of the ground water-table must continue. The history of older countries in this regard, however, does not warrant such prophecies. A review at the expense of repetition may be desirable in the way of a comparison of water demand and water supply.

¹ Literary Digest, Vol. 48, No. 2, p. 59.

270. Crop needs. — McGee says, "In ordinary farming, the agricultural duty of water is to produce one thousandth of its weight in useful crops" and "on ordinary soils the water required for full productivity is about 60 inches (5 feet) per year."¹

England leads the nations in acre yields of grains. The average yield of wheat (1902–1911 inclusive) was 33 Winchester bushels (41.25 American bushels) to the acre.

B. C. Wallis says, "In England wheat is not grown well where the rainfall exceeds thirty inches," and again, "As regards rainfall, the annual precipitation of Ohio is greater than that of Cheshire" (England). The maximum average yield of wheat in Ohio for any year 1870–1911, occurred in 1910, and was 16.2 bushels to the acre.² Undoubtedly during the same period there occurred, in Ohio, individual yields exceeding 40 bushels to the acre, indicating the possibilities with present actual rainfall.

According to King, 12 acre-inches, under the most favorable conditions, may be expected to produce 40 bushels of wheat to the acre. It would produce over 70 bushels of corn, or about 78 bushels of oats, or about 55 bushels of barley to the acre.³ These citations are made to show the range of possible water service, in ordinary, good, and ideal practice in crop production.

271. Animal needs. — The average adult person probably uses less than one ton of water per annum for food and drink. Assuming that he used a barrel of water a

¹ Subsoil Water of Central United States, Yearbook, 1911, pp. 479–490. Also the Agricultural Duty of Water, Yearbook 1910, pp. 169–175.

² Yearbook, 1911, p. 535.

³ King's Physics of Agriculture, p. 141.

week, for all other purposes, the total water used for an individual would amount to 10 tons per annum.

Farm animals consume from 100 to 150 pounds of water daily for each 1000 pounds of animal. Dairy animals producing milk probably consume not far from 100 pounds of water daily for each 1000 pounds of weight. It is probably liberal to allow 100 pounds of water a day for each 1000 pounds of meat produced on the farm up to the time it is marketed.

For the purpose of bringing the water thus used on the farm into comparison with the rainfall of a region, and without attempt at accuracy, except to make our allowances for water-use sufficiently large, let us assume a condition for an 80-acre farm.

(a) Dairy animals aggregating 1000 pounds for each acre of farm; or

(b) Meat-or wool-producing animals or horses aggregating 1000 pounds to an acre of farm, in either case requiring 100 pounds of water a day, or 18.25 tons of water an acre for the year;

(c) That there are on the farm eight persons, and that each person shall be allowed 10 tons of water annually, the adult allowance for drinking and other purposes. This amounts to 1 ton to the acre for the whole farm, which, added to the amount allowed for the live-stock, makes a total of 19.25 tons of water to the acre annually. This is equivalent to a little more than one-sixth ($\frac{1}{6}$) of an inch of rainfall.¹ Very few farms are so heavily stocked, and relatively few will be for many years to come. As a matter of fact much of the water used by both persons and animals finds its way back to the soil and is therefore not lost to it.

¹ Compare McGee, Bulletin No. 92, Bureau of Soils, p. 180.

272. The meaning of the lowering of the ground water-table in terms of rainfall. — The greatest mean lowering of ground water-table in any state recorded by McGee is 4.663 feet for ten years,¹ or 5.5956 inches a year. This 5.5956 inches of fall would be counteracted by from 1 inch² to 1.4 inches of rain, depending upon the amount of pore space existing in subsoil or rock.

273. Intelligent soil management needed. — It is very likely that with the most intelligent soil management during the transformation of great regions from a state of nature to a state of domestication (agricultural production), there would have been a readjustment of the underlying ground water-table; but even with the non-agricultural agencies at work (artesian well, mines, municipal wells and the like) the change would not have been so great as it has been had more intelligent and less selfish methods been employed in the agricultural practice of these regions.

274. The case not serious. — But the case is not so serious as many alarmists would have us believe. The rainfall much exceeds that required for our present acreage yields, doubled, trebled, and in some cases quadrupled, in our humid areas. A better seasonal distribution of precipitation, in some regions, could be desired; but even unsatisfactory seasonal distribution may be partly, if not wholly, counteracted by proper soil management methods. The methods to be employed for this purpose will undoubtedly go far toward arresting a further lowering of the ground water-table, and should go far in restoring it toward its original position. The run-off must be decreased; and cut-off must and can be increased.

¹ Bulletin 92, Bureau of Soils, p. 175.

² Waring, *Draining for Profit, etc.*, p. 23.

275. The real relation of drainage to capillary and ground water. — The actual effect of drainage will be to assist to increase both capillary soil water and ground water for reasons that have been discussed in an earlier chapter, but which may be briefly stated as follows :

The largest exclusion of water from the soil occurs where the soil is improperly drained, with proportionate losses by run-off and fly-off (evaporation).

Larger absorption of water occurs where soils are properly drained. The cut-off is increased.

Proper drainage not only brings about a more open structure of the upper soils, but eventually of the lower subsoils as well, so that while the cut-off is greatly increased, a larger percentage of the cut-off will find its way below the tile.

Better tillage is the natural accompaniment of proper drainage, and absorption (cut-off) is further increased, and evaporation (fly-off) is diminished.

276. The experience of other countries. — In England tile drainage has been practiced since 1764, and is one of the factors placing that country first among the countries of the world in acre yields of cereals. The greatest agricultural countries of continental Europe have been champions of drainage for many years. A lowering water-table is not, at the present time, a matter of alarm with any of them.

277. Optimism. — “The chief cause of the lowering of subsoil water is remediable . . . is bound to be remedied. It [the lowering] can be prevented . . . it is prevented in every carefully worked garden, on every intensively cultivated farm, on every well kept lawn, . . . Each farm should be made to take care of all the water falling on it during the entire year.”¹

¹ McGee, Bulletin 92, Bureau of Soils, U. S. Dept. Agric.

CHAPTER XIII

DRAINAGE AND CLIMATE

A RATHER general opinion is current that the climate of this country, or at least of certain parts of it, is undergoing a change. But while there is general agreement that change is taking place, there is a variety of opinion as to the kinds of change and the causes thereof. This opinion includes:

Changing rainfall — in some cases increasing and in some cases diminishing;

Changing temperature — summers are hotter or colder, the winters are colder or warmer.

278. Diminishing rainfall. — The theory that our annual rainfall is decreasing seems to be very commonly accepted. In certain parts of the Upper Missouri Valley, however, the opinion is prevalent that the annual precipitation is increasing, that the "rain belt," as they say, is moving westward, so that regions once lacking sufficient rainfall to support a reasonable crop are now able to produce fair returns.

Where a decreasing rainfall is supposed to be occurring, the decrease is charged to one or all of three things: (1) the destruction of forests; (2) the transformation of great prairie into agricultural areas; (3) the draining of areas, large and small, of wet and semi-wet lands, and of ponds and lakes.

The chief reasons offered in proof of a diminishing

rainfall are: (1) the apparently insufficient moisture supply during most growing seasons; and (2) the falling ground water-table and drying up of springs, discussed in a previous chapter.

Unquestionably, the insufficient water supply for growing crops must be charged, very largely, to carelessness and the unintelligent methods employed in soil and crop management. The falling of the ground water-table and the failing of springs are not necessarily due to diminishing rainfall, as was shown in previous chapter.

279. Floods and their relation to rainfall. — The occurrence of floods is sometimes offered as a proof of an increasing rainfall. Summer floods, and sometimes winter floods, are the results of erratic or unusual rainfall, excessive or long continued or both. The Paris flood of January, 1910, was due to heavy rainfall which had been preceded by rains sufficiently heavy and long continued completely to saturate the soil.¹ The magnitude of this flood was such that the Seine River carried thirty times its normal volume of water at twenty times its usual speed. At the time of the Dayton flood in March, 1913, a rainfall of 5 inches occurred in one 24-hour period over the Miami basin, and a total of 8.8 inches in one week.² On June 17, 1915, at one point in the middle Missouri Valley flood district, 5.78 inches of rain fell in nine hours.³ For the month of June the rainfall at Columbia, Missouri, was 9.11 inches; at Topeka, Kansas, 9.10 inches; at Iola, Kansas, 8.56 inches and at Kansas City, 7.88 inches. These erratic rainfalls, however, cannot be accepted as evidence that the mean rainfall of any region is increasing. Erratic rain-

¹ Scientific American, Vol. CII, No. 8, p. 164.

² A. J. Henry, Weather Bureau, Bul. Z, 1913.

³ P. Conner, M.W.R., Vol. XLIII, No. 6, p. 28.

falls apparently have always occurred and may be expected to continue to occur.

280. The relation of forests to floods. — “The most important effect of forests on climate is the economic conservation of precipitation, diminishing the intensity of floods by the restriction of flow-off [run-off], and by shading the snow deposited during the winter from the increasing sun of spring and early summer. . . . Investigation in Germany and India seems to indicate that there is an appreciable increase in rainfall as a result of reforestation.”¹ Moore, however, does not give figures and uses the term “seem to indicate.”

Unwise deforestation is, in numerous cases, a serious factor in augmenting the destructiveness of floods.

281. The relation of drainage to floods. — It is sometimes charged that drainage, both open and tile, increases the destructiveness of floods. It is possible that this assertion might be proved in a few cases. In general, drainage should materially lessen the destructiveness of floods. Drainage increases the cut-off. With good methods of tillage, the cut-off is further increased. With ordinary rains, the complete and long continued saturation of the above-tile soil is prevented; so that the net cut-off is increased and the net run-off is considerably controlled by the tile, and even by the open drain. (See paragraphs 77–83.)

282. Observations concerning rainfall. — “There are few places in the Western Division [of England] where the rainfall is less than 35 inches . . . in the low ground about the mouth of the Thames estuary, and around the wash, the mean annual rainfall is less than 25 inches.”²

¹ Willis L. Moore, *Cyclopedia Americana*, Vol. 5.

² *Encyclopædia Britannica*, *Climate of England*.

The mean annual rainfall at the Greenwich Royal Observatory, according to the records 1815 to 1865 (55 years),¹ was 24.98 inches, and if the five-year period 1820 to 1824 is omitted, the mean rainfall was 24.4 inches. The mean rainfall at Greenwich, 1825 to 1869 inclusive (45 years), was 24.05 inches. It may be objected that England is small in area and subjected, in large measure, to ocean environment.

A study of precipitation records reveals the fact that mean annual rainfall varies in large cycles and that apparently the mean of one cycle differs little from that of another. The ground, therefore, for passing judgment on diminishing or increasing rainfall is insufficient.

283. Drainage and rainfall. — The weather records of Great Britain do not indicate a diminishing rainfall. Meteorologists of this country do not admit an actually diminishing rainfall in any part of the country, due to drainage or any other cause. The only relation, therefore, that seems possible between drainage and rainfall is that previously expressed, viz.: the conservation and utilization of the precipitation that comes in the form of rain or snow.

284. Changing temperature. — Students of climate assert that there are no marked permanent changes occurring in the mean temperature of any part of the world, so far as records show. There may occur very marked variations for a year or month. Taken in ten-year periods for a series of years, the means for these periods will not vary greatly from each other. The same may be said of the temperature of any month by periods. The following table includes the mean temperatures for the

¹ Dempsey and Clark, *Drainage of Lands, etc.*, p. 101.

months of December, January and February in New York City for thirty-six years, 1872 to 1907 :¹

TABLE XXII

MEAN TEMPERATURE FOR THE MONTHS OF DECEMBER, JANUARY,
AND FEBRUARY

1872 . . .	29.8° F.	1890 . . .	40.7° F.
1873 . . .	28.1° F.	1891 . . .	34.5° F.
1874 . . .	34.1° F.	1892 . . .	35.0° F.
1875 . . .	27.4° F.	1893 . . .	28.1° F.
1876 . . .	32.9° F.	1894 . . .	33.1° F.
1877 . . .	29.4° F.	1895 . . .	30.7° F.
1878 . . .	35.3° F.	1896 . . .	31.6° F.
1879 . . .	28.9° F.	1897 . . .	31.4° F.
1880 . . .	37.8° F.	1898 . . .	33.7° F.
1881 . . .	27.7° F.	1899 . . .	30.7° F.
1882 . . .	35.6° F.	1900 . . .	33.7° F.
1883 . . .	30.5° F.	1901 . . .	30.8° F.
1884 . . .	31.7° F.	1902 . . .	30.7° F.
1885 . . .	29.0° F.	1903 . . .	32.4° F.
1886 . . .	31.0° F.	1904 . . .	26.4° F.
1887 . . .	31.5° F.	1905 . . .	26.8° F.
1888 . . .	31.3° F.	1906 . . .	35.4° F.
1889 . . .	33.9° F.	1907 . . .	29.8° F.

These means are again averaged for ten-year periods and stand as follows :

1872 to 1881	31.14° F.
1882 to 1891	32.97° F.
1892 to 1901	31.88° F.
1898 to 1907	31.04° F.

It may be argued that the nearness of the ocean might equalize the temperature of New York City. The following table is even more interesting than the one above :

¹ Walter H. F. Grau. Harper's Weekly, Vol. 52, No. 2713, (1908), p. 8.

TABLE XXIII

MEAN TEMPERATURE FOR THE MONTHS OF DECEMBER, JANUARY,
AND FEBRUARY

	1854-5 TO 78-9	79-80 TO 1903-4
Cincinnati	34.8	34
St. Louis	33.5	33.5
Cleveland	28.2	28.2
New Orleans	55.2	55.5
Chicago	25.0	25.5
New Bedford, Mass.	29.1	29.5
Washington, D.C.	34.2	34.9
Charleston	51.1	51.3 ¹

285. Changes in frost dates. — It is said by old residents of southern and central Michigan and other originally forested parts of our country, that with the cutting away of the timber and draining of the lands of these regions, the periods between late spring and early fall frosts have been greatly lengthened, so that certain crops can now be grown that could not be grown in pioneer days. Records are not easily found to verify these claims. The claims, however, do not seem unreasonable. Very definite relation exists between air drainage and the occurrence of frosts. The practical orchardist recognizes the great importance of air drainage in the selection of an orchard site. After the first light frost, the affected areas are found to occupy the depressions and ravines of the field, and are as clearly defined as would be the shores

¹ Walter H. F. Grau, Harper's Weekly, Vol. 152, No. 2713, p. 8.

Data procured in part from "reliable private records," and from those of voluntary observers coöperating with the Smithsonian Institution.

of ponds in the depressions and streams in the ravines, and the more severe the frost, the higher the shore line, all of which shows that 32-degree air gravitates and displaces air of higher temperature.

286. Wooded areas and frosts. — Obstructions to the ready gravitational movements of air increase the tendency to frosts, whether these are ridges of land or stretches of wood. In cultivated areas, surrounded by woods, frosts often occur that probably would not if the timber on the lower side were removed.

287. Drainage and surface temperature. — While drainage might not be expected appreciably to affect the mean temperature of a region, it undoubtedly does very materially affect the temperature of the surface soil, by greatly reducing the loss of heat by evaporation, and by lowering its specific heat; and it is not unreasonable to conclude that this all might result in lengthening the period between late spring and early fall frosts. (See paragraphs 56 and 57.)

CHAPTER XIV

DRAINAGE LAWS

NUMEROUS questions arise concerning the rights of individuals who desire to drain their lands. An attempt will be made in the following pages to state, briefly, certain facts in law concerning the rights of property owners to drain their lands, and the methods of procedure under certain conditions.

288. The right of the individual to drain his property when it lies adjacent to a natural water course. — The law of Iowa reads: "Owners of land may drain the same in the general course of natural drainage, by constructing open or covered drains, discharging the same into any natural water course, or into any natural depression, whereby the water will be carried into some natural water course, and when such drainage is wholly upon the owner's land he shall not be liable in damages therefor to any person or persons, or corporation." The law of Illinois is identical, except that it specifies also that the drainage may be discharged "into some drain on the public highway with the consent of the Commissioners thereto."

The right of an owner of land to discharge the drainage waters from his farm into natural water courses, after the manner indicated in the above quoted law, would probably be sustained in most states, if not in every state. It is probable, however, that if any owner of land should

discharge the sewage of his home or barns into his drain system, the discharge of such drainage into a natural waterway could be prevented by due process of law.

289. The right of an individual to drain his property when not lying adjacent to natural water courses. — In some states at least, the law gives the owner of land the right, when necessary, to drain across the property of another party in order to reach a natural water course or drain. Usually this is done by the use of tile drains. It is frequently possible for the party having land to drain, and the party through whose land the drainage must be conducted, to arrive at an agreement by which the work may be done. It would be a wiser precaution, always, to have such an agreement in writing and properly witnessed. It should be properly signed at least.

When such an agreement cannot be entered into, or the party across whose land the drainage must be conducted objects, the law usually provides a procedure that must be followed. The procedure must be before a court or an arbitration commission. This court or commission must decide first, whether it is necessary for the party desiring to drain his land, to cross his neighbor's land for an outlet and if they decide affirmatively, they must determine, directly or otherwise (through an employed engineer, "viewers," or other), the course the drain shall take and the damages the neighbor shall receive for the crossing of his land. The law gives to the land-owner the right, directly or through a contractor, to construct the drain, and at seasonable times thereafter to enter the neighbor's premises to inspect and repair the drain.

There are two provisions in the law of New York for the drainage of wet land for agricultural purposes, as explained by Fippin in the Cornell Reading Course.

“The first of these is under the Agricultural Drainage Statute, Consolidated Laws of the State of New York, chapter 15, as amended by chapter 624 of the Laws of 1910. The second provision is contained in the act establishing the State Conservation Commission, Consolidated Laws, chapter 65, article 8. The general procedure is the same under both acts, and the cost of securing the right of way and constructing the drainage ditch is assessed against the land benefited. These laws usually deal with the large outlet canals, but are applicable in securing an outlet for the drain from a single farm.

“In a general way, advantage may be taken of the natural fall of the land in establishing an outlet for a drainage system, and adjoining property owners must provide for the drainage water so discharged as surface water. As yet no such obligation is recognized to apply to water collected and discharged by tile drains except as it reaches the adjoining property as surface water in a natural drainage course. There are very few cases of drainage that are not provided for in the existing drainage laws of the State.”

290. The right of a group of individuals to drain. — When a tract of land, embracing the holdings of more than one person, requires drainage, and when few, if any, of the holdings lie adjacent to a natural water-way or drainage course, and where the topography is such that they must, or may, discharge their drainage waters along a common course, this tract may be organized into a drainage district. The purposes of such a procedure include economy, efficiency and justice, both in construction and up-keep. Several things must be considered. The size of the mains or sub-mains increases as they approach the outlet for the district. In some, probably most, cases

the mains become open ditches, often of considerable size, and the expense of building or installing may be great, both because of their size and depth. Sometimes a drain must cross a farm that will derive little, if any, benefit from the system, or even if it should derive benefit, the right of way for the ditch, if it is an open ditch, may require a considerable acreage of land, or may cross the farm in such a way as to interfere with the operations of the farm and in this, and other ways, result in lessening the value of the farm. Some of the land-owners may object to the expense to the district; some may feel they would derive no benefit from such a system of drains.

The laws governing the procedure in establishing and putting into operation a drainage district are drawn to equalize cost and assure justice to all concerned. Excepting in minor details, the method of procedure is very similar in the several states, and is about as follows:

291. A petition must be prepared. — A petition must be signed, in most states, by a majority of the land-owners of the proposed district. In Illinois the petition must be signed by at least one-half of the land-owners who together must own at least two-thirds of the land of the district, or by at least two-thirds of the land-owners who together must own at least one-half of the land of the district. In Iowa the petition may be signed "by one or more land-owners whose lands will be affected by or assessed for"; in Minnesota by "one or more of the land-owners whose lands will be liable to be affected by or assessed for the construction of the same," or "by the supervisors of any township" and so on. In Michigan the number of petitioners must equal one-third of the number of persons owning land through which the proposed drain will pass, and they must be freeholders liable

to assessment if the drain is built. Usually certain details must be observed. In some cases the petition must be accompanied by, or must contain, a description of the lands to be affected or benefited by such a drainage system. In some cases it must declare that it is the opinion of the petitioners that the enterprise is necessary to the public good, or possibly the public health. In some cases it must be accompanied by a guaranty that the preliminary expense will be met by the petitioners, if, after due examination, the petition is denied. In Iowa this petition must be presented to the county board through the county auditor; in Minnesota, to the county board or a district judge, depending upon whether the drainage district lies within one county or in two or more counties. In Illinois, the petition is presented through the town clerk to the highway commissioner of the town or towns in which the proposed district lies. This in counties under township organization. In counties not under township organization the petition must be presented to the clerk of the probate court. In Michigan the petition must be presented to the county drain commissioner.

292. Action upon the petition. — The law usually makes provision for the calling of a meeting which may be followed by others, called or adjourned. Lawful notice of such meeting must be posted, published, or mailed, with a view to having all parties directly interested informed of the time and place of the meeting. At the first meeting the legality of the petition must be established. Usually, if there are any errors, provision is found in the law for their rectification. In some states, any person who has not already signed the petition may do so, but no person who has signed the petition may withdraw his name, unless he can show that he signed it

through misunderstanding, or because of some misrepresentation. If fraud is discovered in the petition, or if it has not been prepared in accordance with law, it must be dismissed or denied.

293. Objections must be heard. — In all cases, objections to the proposed system must be heard and considered. Usually these objections may be offered only by parties whose lands will be assessed in case the system is constructed or who feel that the enterprise will work injury to their lands. In Illinois, and probably other states, no person who has signed a petition may offer objections. In Illinois, the commissioners may administer oath and listen to controversial evidence.

294. The proposed district must be examined. — If the body or person to whom the petition is presented favors the petition, provision is made for the examination of the proposed district. Sometimes this is done directly by the petitioned body and sometimes by an engineer or commission appointed for the purpose. In this examination, changes may be made in the outline of the district. Lands may be included not indicated in the petition, and in certain instances, lands may be excluded that were indicated in the petition. The proposed course of the mains should be examined into and may be changed. Usually a map of the district and an estimate of costs are prepared; all of which must be submitted to the deciding body or person.

295. The organization of the district must be authorized. — With the results of the examination, map of the district, and estimates of cost at hand, if it appears that the expense of organizing the district and constructing the system of drainage exceed the benefits to be derived therefrom, the petition should be finally denied. If

the benefits to be derived exceed such expenses, the petition should be granted, and the legal organization of the district authorized, and all parties whose property will be taxed in the execution of the work must be legally notified.

296. The work of construction. — The execution of the work of construction must be done under authority. It includes the perfecting of the plans for the system of drainage; the construction work, directly or through contractors; the levying and collecting of taxes to pay for the same; sometimes the borrowing of money and the issuing of bonds for the same; the auditing and the authorizing of the paying of bills, or certain parts of them as they become due. After the work is completed, the repair and up-keep of the system must be looked after. A district drainage enterprise is sometimes both extensive and expensive, so that it is impractical to meet the expense by a single tax levy. In such a case, the payment may extend over a number of years, and since the work must be paid for as rapidly as completed, it becomes necessary, in such cases, to borrow money and issue a bond, or bonds, for the payment of the same. In Michigan all of this work is looked after by the county drain commissioner. In Illinois three drainage commissioners are elected for this purpose. In Iowa, the county board of supervisors directs the finances and employs an engineer to supervise the work. In Minnesota the county board directs the finances, while the construction is supervised by an engineer appointed by the county board or district judge. The later supervision and up-keep is in the hands of the county drain commissioner in Michigan; of a board of three commissioners elected by the district in Illinois; by the board of county supervisors in Minnesota.

297. Grievances. — The law usually makes abundant provision for the satisfying of aggrieved parties. An owner of land who thinks that he is not offered proper compensation for right of way privileges, or other damages resulting from the passage of a drain through his property, or who may think that the taxes apportioned to him are unjust, will find provision in the law by which he may appeal from the first decisions. In some cases appraisers are appointed to pass upon the question of damages. In some cases provision is made for taking the matter before a court and jury. When assessment and apportionment of taxes are questioned, the matter is sometimes decided by a board of review. It is probably usually true that when, in cases of appeals of this kind, the damages are not increased, or the taxes are not reduced, the party so appealing must stand the expense resulting therefrom. It is true in some states at least.

298. Time a factor. — Time seems always to be recognized as an important factor in the proceedings leading to the establishment of a drainage district. The law prescribes a minimum, and frequently a maximum period of time that must elapse in the calling of meetings, in the sending or publishing of notices, in the execution of work of committees, commissions, or engineers, in the filing of claims for damages, and in the time that must elapse from the time of the dismissal of one petition until another petition for a similar enterprise may be filed.

299. Records. — The law recognizes the importance of accurate and complete records. It is probably true that in all cases, petitions, with all supplemental information and data required with them, must be filed or recorded. The same thing is true of the minutes of meetings, hearings, protests, claims, estimates, maps, and the like.

300. Mutual agreements. — In some, if not in all, states the law gives to any group of freeholders, desiring to organize a drainage district, the right to enter into a mutual agreement for the organization of such, and for the laying out of the system and the execution of the work and payment therefore. It is probably true that such an agreement must in all cases become a matter of record, and should be drawn with care, and be specific in the points of agreement. The work of construction in such cases is usually, if not always, required to be done under the same authority as in cases in which petitions are presented and the work carried out in the ordinary way. In the case of mutual agreement, however, time and expense and annoyance are saved.

301. Unlawful acts; penalties. — Certain acts relating to draining and drainage are unlawful in most states, and are classed as misdemeanors. In Minnesota it is not lawful:

To willfully or negligently obstruct or injure any work constructed under the provision of certain drainage laws;

To allow such work to be injured or obstructed by livestock;

To divert water from its proper channel;

To change location of, or markings on, stakes set and marked by the engineer in charge of any drainage work (unless authorized by said engineer to make such changes);

To dig or construct, or cause to be dug or constructed, drains emptying their water into county or district drains, without having first obtained proper permission to do so.

To attempt to prevent or interfere with the entrance upon any tract of land by the viewers, county commissioners, and the engineers to do any act necessary

in connection with their duties in any piece of drainage work.

Persons committing any of these acts may be found guilty of a misdemeanor and may also be held liable for losses that may result to any individual or corporation from such act, even to treble damages.

An officer who neglects, or fails, or refuses to perform duties imposed upon him by law, may be guilty of misdemeanor, and may be liable to all persons or corporations by such act, even in treble damages.

APPENDIX

LABORATORY PRACTICE

THE following eighteen experiments, some of which have more than one part, are prepared to demonstrate some of the more important facts concerning soil conditions and drainage, and these are likely to suggest others to both teacher and student. They have been used, slightly modified in some cases, by the writer.

EXPERIMENT 1

Distribution of Capillary Water in Columns of Soil

(A) The material required for this experiment consists of:

1. A number of threaded 6-inch sections of $1\frac{1}{2}$ -inch brass tubing as illustrated in Fig. 91.
2. Three-inch circular filter paper.
3. Small pieces of strong cheese-cloth, 4 inches square.
4. Light strong cord.
5. A small strong granite-ware pan with creased bottom. Instead of a granite-ware pan, a small block of some non-absorptive material may be used.

6. A $\frac{3}{4}$ -inch round soft-wood rod, 10 or 12 inches long.

(B) To perform the experiment:

1. Carefully vaseline the base of the threads of twelve of the threaded sections of tubing and screw them to-

gether. This will make a cylinder 6 feet long. It may be desirable in some cases to use fourteen or even eighteen sections.

2. Place a piece of filter paper over the lower end of the cylinder, and over this place a piece of cheese-cloth, bringing the edges of both filter paper and cheese-cloth up over the cylinder, and strongly tie in place.

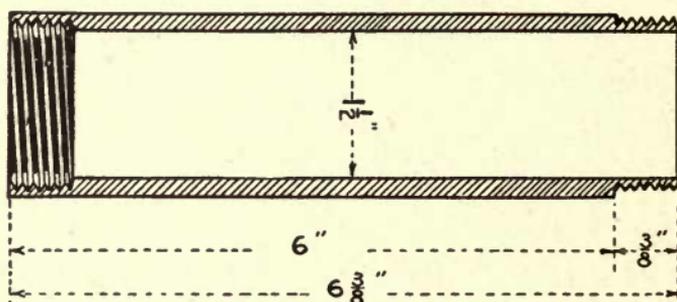


FIG. 91. — Threaded section of brass tubing used in studying distribution of water in soil columns.

3. With colored pencil, number the sections of the cylinder 1, 2, 3, and so on from top to bottom.

4. Fasten the cylinder in an upright position with the bottom resting upon a pan, or other support.

5. Fill the cylinder with graded fine sand and settle by tapping until settling ceases. For uniformity of filling, an excellent method is to introduce the end of a large funnel into the top of the cylinder and introduce the sand into the cylinder through the funnel, pouring the sand into the funnel at such a rate that the funnel will not become empty at any time during the filling. If the funnel can be held, during this process, so that the lower end of the stem shall be just below the top of the cylinder, the filling of the upper section will be more nearly uniform with that of the lower sections. To produce the settling,

tap the walls of the cylinder with the wood rod, distributing the tapping over the whole length of the cylinder. The tapping should not be severe enough to batter the walls of the cylinder.

6. After the settling has ceased, carefully brush the threading of the top section, carefully vaseline at the base, and add two empty sections.

7. Introduce water into the top of cylinder, being careful to keep the upper sections nearly full of water, until water begins to percolate from the bottom.

8. Place a piece of cheese-cloth, or some other covering, over the top of the cylinder and allow to stand 48 hours.

9. At the end of 48 hours, carefully and quickly separate the sections by unscrewing; carefully wipe vaseline from joints.

10. Place each section in a dry tared tray, numbered to correspond with the number of the section.

11. Carefully weigh each tray with contents and carefully record weight.

12. Dry to constant weight and weigh and record weight of each tray and contents.

13. Remove, carefully wipe and weigh each section, and carefully record its weight.

14. From the data thus obtained determine:

(a) The weight of dry soil in each section.

(b) The weight of water contained in each section before drying.

(c) The percentage of water in each section. (The percentage is obtained by dividing the water lost in drying by the dry weight of soil.)

15. Plot curve of distribution of water in the column of soil in the cylinder at the end of 48 hours after saturation.

EXPERIMENT 2

The Influence of Subsoil on the Distribution of Capillary Water in the Overlying Soil

Conduct the experiment in every particular as in Experiment 1, already explained, except that in paragraph 4 of directions, the cylinder be placed on the surface of a bucket full of dry sand of the same kind and grade as that used in the cylinder.

EXPERIMENT 3

The Influence of a Heavy Subsoil on the Distribution of Capillary Water in the Overlying Soil

Conduct the experiment in every particular as in Experiment 1, except that in paragraph 4 of directions, the cylinder be placed upon heavy clay. (If the cylinder can be placed upon bare ground, of a nature heavier than the sand in the cylinder, preferably heavy clay, the same or similar results should be obtained. In this case the filter paper may be dispensed with.)

EXPERIMENT 4

The Influence of a Layer of Gravel or Coarse Material on the Distribution of Capillary Water in the Overlying Soil

Conduct the experiment in every particular as in Experiment 1, except that the fourth section from the bottom be filled with very fine gravel, or very coarse sand, and that the gravel or sand be moistened before it is introduced. In this experiment, the lower four sections

should be put together, the filter paper and cheese-cloth carefully tied in place, and the lower three sections filled with sand and settled, adding enough sand so that the settled sand shall stand slightly above the joint between sections 3 and 4 from the bottom. Then the fourth section should be filled with the gravel or coarse sand. After this, the remaining sections which have been properly put together should be screwed on to section 4 from bottom, first being careful to clean and vaseline the upper threads of section 4.

EXPERIMENT 5

Surface Tension

(A) The materials needed for this experiment are :

1. A small dish of fine sand.
2. A shallow dish or watch glass.
3. A beaker of water.
4. A heated clean iron surface.

(B) To perform the experiment :

1. Place a small quantity of water in the dish or watch glass.
2. Slowly pour fine sand into the water in the dish until more sand has been poured in than the water will moisten.
3. After thirty seconds invert the dish to permit the unmoistened portion of the sand to fall away.

Observe: The dish may be held in any position and the moistened sand will not fall away from it. Why?

4. Set the dish in position and with a sharpened pencil or rod break the sand into small masses of various sizes. It will be found that masses of considerable size may be lifted upon the point of the pencil or rod without breaking.

Why? Draw a sketch to illustrate your idea of how the particles of sand are held together. (See Fig. 17.)

5. Place one of the masses of wet sand upon the hot iron surface and note its behavior. After a few seconds the mass begins to collapse. Sometimes it collapses a part at a time. Sometimes the whole mass suddenly collapses. In either case the grains of sand fall apart and scatter about over the heated surface. Why?

6. Lift a mass of the wet sand upon the point of a pencil and carefully bring it over a vessel full of water; then slowly and carefully lower the mass till some point of it comes just in contact with the surface of the water, and note what happens. Suddenly a portion of the mass, or possibly all of the mass, breaks away from the point of the pencil and settles to the bottom of the glass, but it will be observed that within the body of water the grains of sand become independent of each other and spread apart as they settle.

Why do they break away from the pencil?

Why do they spread apart as they settle?

EXPERIMENT 6

Surface Tension

The experiment (5) may be repeated using loam and fine clay. If fine clay and frequently if fine loam be used, the behavior of the moist mass, when placed upon the hot surface, will be different from that of the mass of fine sand, and will illustrate another very important action of the capillary film.

EXPERIMENT 7

Surface Tension

(A) 1. Introduce a small amount of water (one or two grams) into a watch glass or other shallow dish.

2. Pour sand steadily, and in a small stream at one point, into the water until the water is completely taken up by sand. Pour in an excess of dry sand. The sand mass will be found to take a form similar to that shown in Fig. 18 of the text.

3. After 15 seconds, the dish should be slowly inverted to permit the dry sand to fall away from the surface of the mass in the dish.

4. The dish may now be held in any position and the pyramid of moist sand will usually not break. Why?

5. Draw a diagram or sketch to show the manner in which, as you understand it, the pyramid is kept in position.

(B) 1. Place the dish in position on a stand or table.

2. Pour a very small amount of water down the inner surface of the dish. The pyramid of moist sand will collapse. Why?

EXPERIMENT 8

Specific Heat of Wet and Dry Soils

Where the apparatus is available, determine the specific heat of wet and dry soils, using Mosier and Gustafson's method as described on page 40 of their Soil Physics Laboratory Manual, or McCall's, as described in his Physical Properties of Soil, p. 74.

EXPERIMENT 9

Effect of Evaporation on Soil Temperature

1. Fill to within a quarter inch of the top, three 1-quart granite-ware pans (or any three vessels of equal size and shape), with any soil of the same kind, preferably a sandy loam for this experiment.

2. With wax pencil or otherwise mark the pans 1, 2, and 3.

3. Place a small piece of filter paper upon the surface of the soil in pans 2 and 3.

4. Upon the filter paper in pan 2, pour an amount of water equal to 20 per cent of the weight of the soil in the pan.

5. Upon the filter paper in pan 3, pour water until the soil is slightly more than saturated.

6. Place a cover on each of the three pans and set the pans together, either in the laboratory or out-of-doors, where the temperature will remain fairly constant, and permit to stand till the following morning.

7. Remove covers and determine the temperature of the soil in each pan by inserting a thermometer bulb just below the surface, and record temperature in each case. It is desirable to have a thermometer for each pan and to allow it to remain in position during the period of the experiment.

8. At the end of each hour, for three to six hours if possible, again determine the temperature of the soil in the same manner and record temperature.

9. Plot curves of temperature for the three pans.

EXPERIMENT 10

Effect of Drainage on Germination

1. Have prepared a galvanized iron pan 1 foot by 2 feet by 6 inches deep.

2. Have prepared a frame of galvanized iron 1 foot by 2 feet by 6 inches deep. This frame will be, in construction, in every way like the pan described in 1, except that it has no bottom.

3. Preferably out-of-doors, excavate in a loam soil two openings of sufficient size, one to receive the pan and the other the frame, so that the upper edge of pan and frame lie just flush with the surface of the ground, being careful also to have selected a spot so that when the pan and frame are placed, their tops shall stand absolutely level.

4. Thoroughly mellow and mix the soil that was removed in excavating, and introduce a sufficient amount into the pan and frame to well fill, packing lightly in the filling.

5. After pan and frame have been filled a few hours, determine the temperature of the surface soil of each by inserting the bulb of a thermometer to the same depth below the surface — say $\frac{3}{4}$ of an inch. Record temperature.

6. Carefully measure or weigh into the pan a sufficient amount of water thoroughly to saturate the soil and record the amount of water so introduced.

7. Introduce slowly and uniformly into the soil in the frame an amount of water equal to that introduced into the soil in the pan.

8. Lay off the surface of the soil in pan and frame into six-inch squares.

9. (a) In the four squares on one side of the pan plant seeds as follows: In the first, 6 good grains of wheat; in the second, 6 good grains of oats; in the third, 4 good beans; and in the fourth, 4 grains of corn. In the other four plant seeds as follows: In the first, which will be adjacent to the wheat, plant 4 grains of corn; in the next, which will be adjacent to the oats, plant 4 beans; in the next, which will be adjacent to the beans, plant 6 grains of oats; and in the next, which will be adjacent to the corn, plant 6 grains of wheat. In planting the seeds place the wheat and oats $\frac{1}{2}$ inch below the surface; place the corn and beans 1 inch below the surface.

(b) Plant the squares in the frame to the same seeds, and in the same order.

10. On the second day after planting, determine and record the temperature for each of the squares in the pan and in the frame.

11. (a) On the 4th, 8th, and 12th days from planting, measure into the soil in the pan enough water to bring the soil to saturation, and record the amount of water used.

(b) Apply slowly and uniformly to the soil in the frame an amount of water equivalent to that just added to the pan.

12. On the 5th day from planting determine and record temperatures as before.

13. Watch carefully for and record the date of the first appearance of plants in each square.

14. Note and record any peculiarities or differences in the behavior of the plants growing under the different conditions.

15. Note and record from time to time the amount of growth made by the plants.

EXPERIMENT 11

Shrinkage of Soils

(A) The apparatus required for this experiment is illustrated in Fig. 92. It consists of:

1. A block of hardwood (A) 6 inches by 6 inches and 1 inch thick.
2. Upon it is mounted, as shown in the figure, a rec-

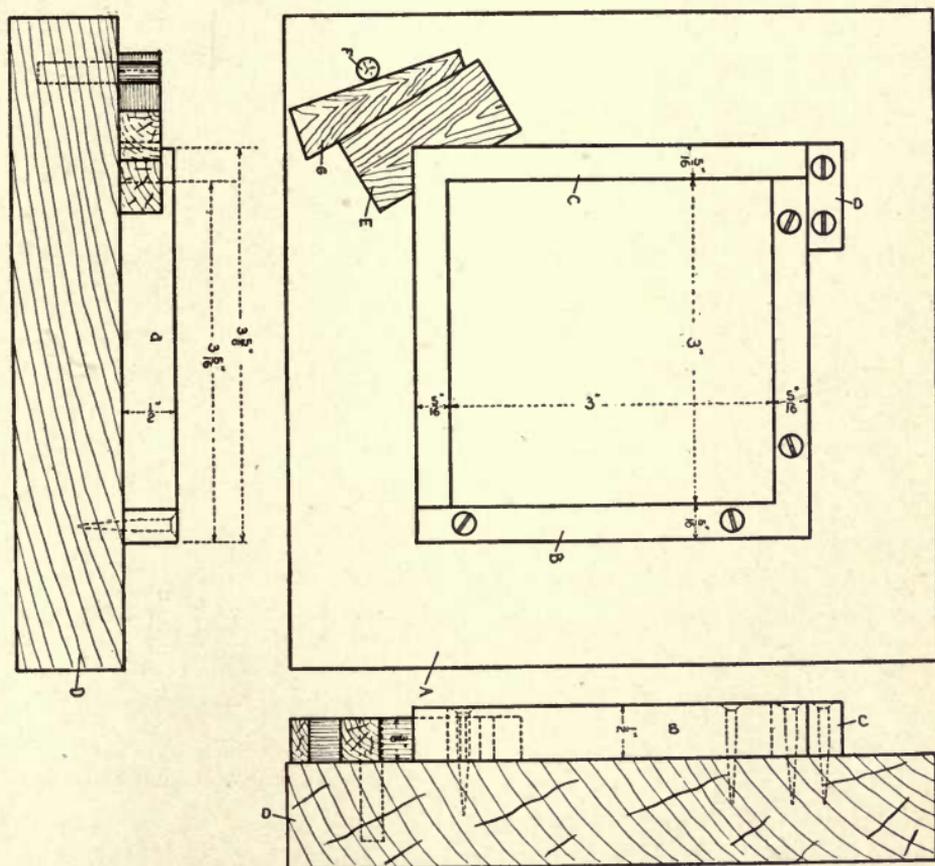


FIG. 92.—Apparatus for studying shrinkage of soils. See description under Experiment 11.

tangular piece of brass (*B*). This piece of brass is $\frac{1}{2}$ inch high and $\frac{5}{16}$ inch thick, with smooth inner surface.

3. A piece of brass (*C*), same dimensions as (*B*), but without screw holes, and not attached to base (*A*).

4. A piece of brass (*D*), $\frac{1}{2}$ inch by $\frac{5}{16}$ inch by 1 inch, attached to base (*A*) as shown.

5. A piece of wood (*E*), $\frac{3}{4}$ inch by $1\frac{1}{2}$ inches by $\frac{3}{8}$ inch, with one edge cut to shoulder upon the piece (*C*) as shown.

6. A metal pin (*F*), $\frac{3}{16}$ inch in diameter, mounted in base as shown.

7. A wooden wedge (*G*), $1\frac{3}{4}$ inches long and $\frac{3}{8}$ inch thick, cut as shown.

8. When the metal piece (*C*) is placed on the base as shown, with the piece of wood (*E*) shouldering upon it, and the wedge (*G*) driven into place, the metal pieces (*B*) and (*C*) thus form a box 3 inches by 3 inches by $\frac{1}{2}$ inch deep.

These metal pieces might be made of babbitt. They may be made of iron but are subject to rust. If made of babbitt, the thickness should not be less than $\frac{3}{8}$ inch.

(*B*) To perform the experiment :

1. Measure out 200 grams of clay soil.
2. Place in dish and add just sufficient water to moisten.
3. Thoroughly knead, or work, until the mass has become thoroughly mixed.
4. It may be necessary to add more clay as the kneading, or working, operation proceeds.
5. Continue the kneading until the water has taken up all the soil it will thoroughly moisten, in other words, until the mass is as dense as it can be made by kneading.

6. Place in the metal frame (*BC*) a piece of cheesecloth sufficiently large to cover the bottom of the frame and the sides.

7. Into the frame introduce the mass of wet soil, packing the soil down thoroughly and filling a little more than flush full.

8. With a sharp straight edge or knife, cut away the excess, leaving the frame just flush full.

9. Remove the wedge (*G*) and carefully remove section (*C*) of the metal frame, and then carefully remove the mass of soil.

10. Place the mass of soil where it will remain at air temperature for two days, then place in drying oven at 100° C., and allow to remain until completely dry.

11. At the end of each 24 hours, measure the dimensions of the mass of soil and make a record of time and measurements.

12. Determine the percentage of shrinkage up to the time of each measurement.

13. Repeat the experiment with the other kinds of soil and compare the results.

EXPERIMENT 12

Puddling Soils

1. Procure an amount of mellow heavy field clay.

2. Carefully dry so that the crummy structure shall not be destroyed, and so that the clay shall not dry in masses.

3. Weigh 25 grams of the dry clay into each of two funnels, having first carefully placed a properly folded filter paper in each funnel and moistened.

4. With cork or wax, carefully close the lower end of one of the funnels.

5. Carefully measure into the funnel that has the lower end of its stem closed, a sufficient amount of water thoroughly to cover the clay in the funnel, and carefully cover funnel with watch glass.

6. Over the soil in the funnel with the open stem, carefully pour an amount of water equal to that placed on the soil in the other funnel, but do not cover with watch glass.

7. At the end of two days remove the watch glass from the first funnel and allow to stand until the soil has become thoroughly dry. The cork or wax may be removed from the lower end of the stem and the funnel may be placed in a warm place to hasten the drying.

8. When both lots of clay have become thoroughly dry, carefully study the two masses with regard to compactness and resistance to crushing.

EXPERIMENTS 13-18

Apparatus

For the four following experiments, the apparatus shown in Fig. 93 will be used. It is practically the same as that devised by King, and illustrated in his *Physics of Agriculture*, p. 293.

It is suggested that tile 1 be a 4-inch cement tile of dry mix in the proportions of 1 of cement to 5 of sand.

That tile 2, be a 4-inch cement tile of wet mix in the proportions of 1 of cement to 3 of sand.

That tile 3 be a 4-inch clay tile of dense texture.

That tile 4 be a 4-inch clay tile of as open texture as can be found.

That tile 5 be a 6-inch clay tile of a texture similar to that of 4.

That the nature of tile 6 be determined by the requirements of the laboratory.

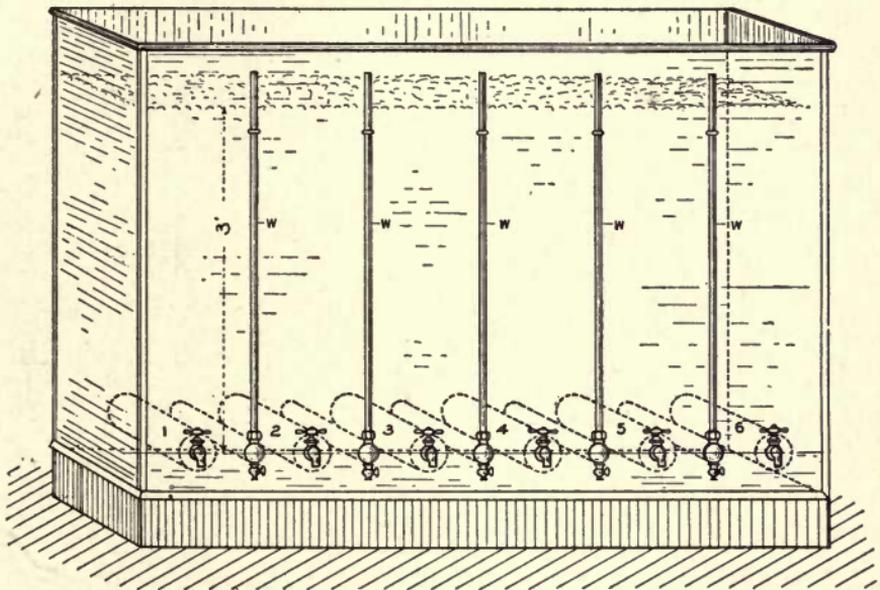


FIG. 93. — Apparatus for studying movement of water through tiles and influence of tile upon ground water. 1, 2, 3, 4, 5, and 6, tile of different sizes and nature, and explained in detail in Fig. 94; *W . . . W*, water gauge tubes connected with 2-inch tile as explained and shown in Fig. 95. See description, pages 238–239.

These tile should rest, as is shown in the figure, in a fine sand which fills the tank to the height of 3 feet above the center of the tile.

Figure 94 shows a tile in cross section and so arranged that water can enter it only through its walls. The legend follows:

- A*, Section of tile.
- B*, Steel or cast iron plates.
- C*, Gaskets.

D, Half-inch gas pipe threaded as shown, and with quarter-inch holes bored in its walls to permit the passage of water.

E, Ordinary pipe cap.

F, Nuts.

G, Coupling to attach faucet to end of pipe.

In putting the apparatus together, the chief thing is to square the ends of the tile so that the gasket and plate will fit fairly snugly before the nut is tightened. The manner of putting the parts together and setting the tile in place in the tank will not be difficult for a mechanic, or indeed the ordinary individual, to accomplish. In setting the tile in place, a bed of the fine sand to be used in filling the tank should first be laid to a sufficient depth that the tile in being placed may rest firmly upon the sand.

Figure 95 shows the manner in which the water in the tank reaches the water gauges :

A is a 2-inch tile. It may be larger.

B, Section of half-inch gas pipe.

C, A collar to carry the section of gas pipe and the gauge seat.

To prevent leaking, the joint between collar and opening in wall of tank should be soldered on the inside.

The tile lies loosely against the inner wall of the tank and is filled with gravel to permit the more ready passage of water from the sand to the section of gas pipe. This tile also is laid in place upon a bed of the sand with which the tank is to be filled later. After the tile are all in place, more sand should be carefully introduced and packed carefully around the sides of each until the sand stands above the center of the tile, after which the tank should be filled to the height of 3 feet above the center of the tile.

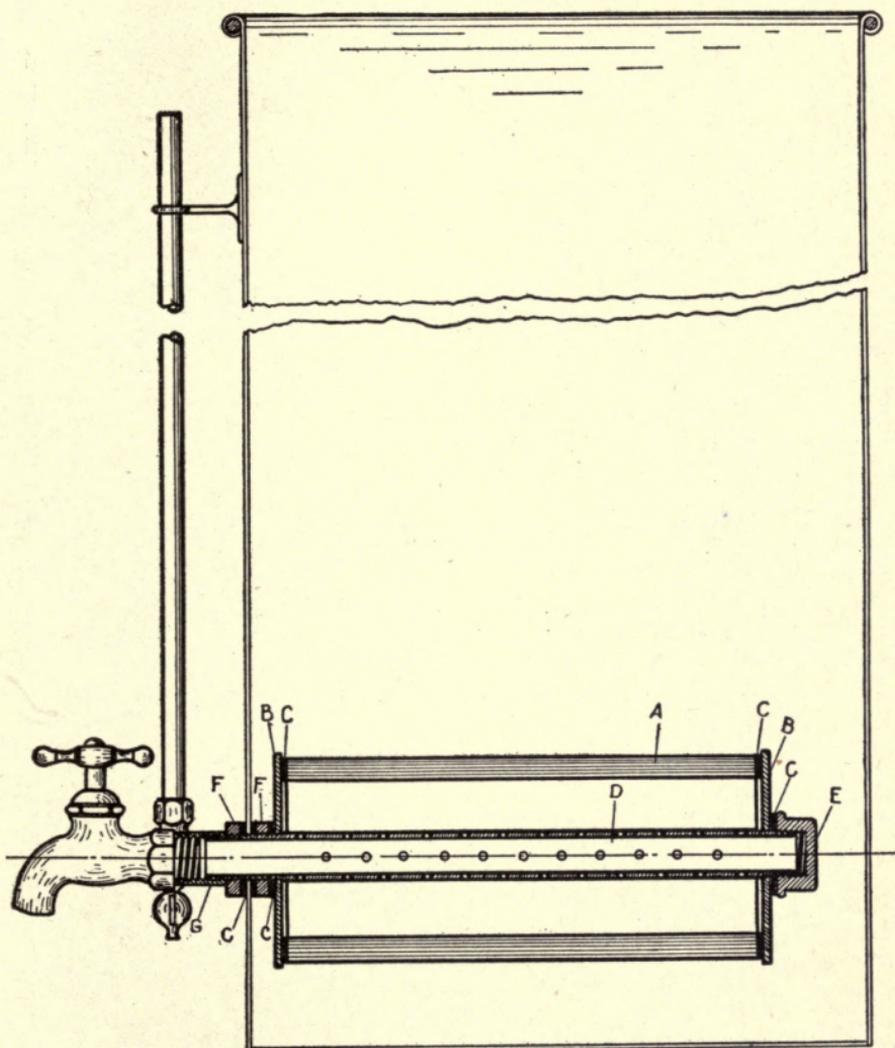


FIG. 94. — Detailed cross section of Fig. 93, showing the manner of setting up tile so that water can enter only through walls. Water gauge is not a part of this detail. See description, page 239.

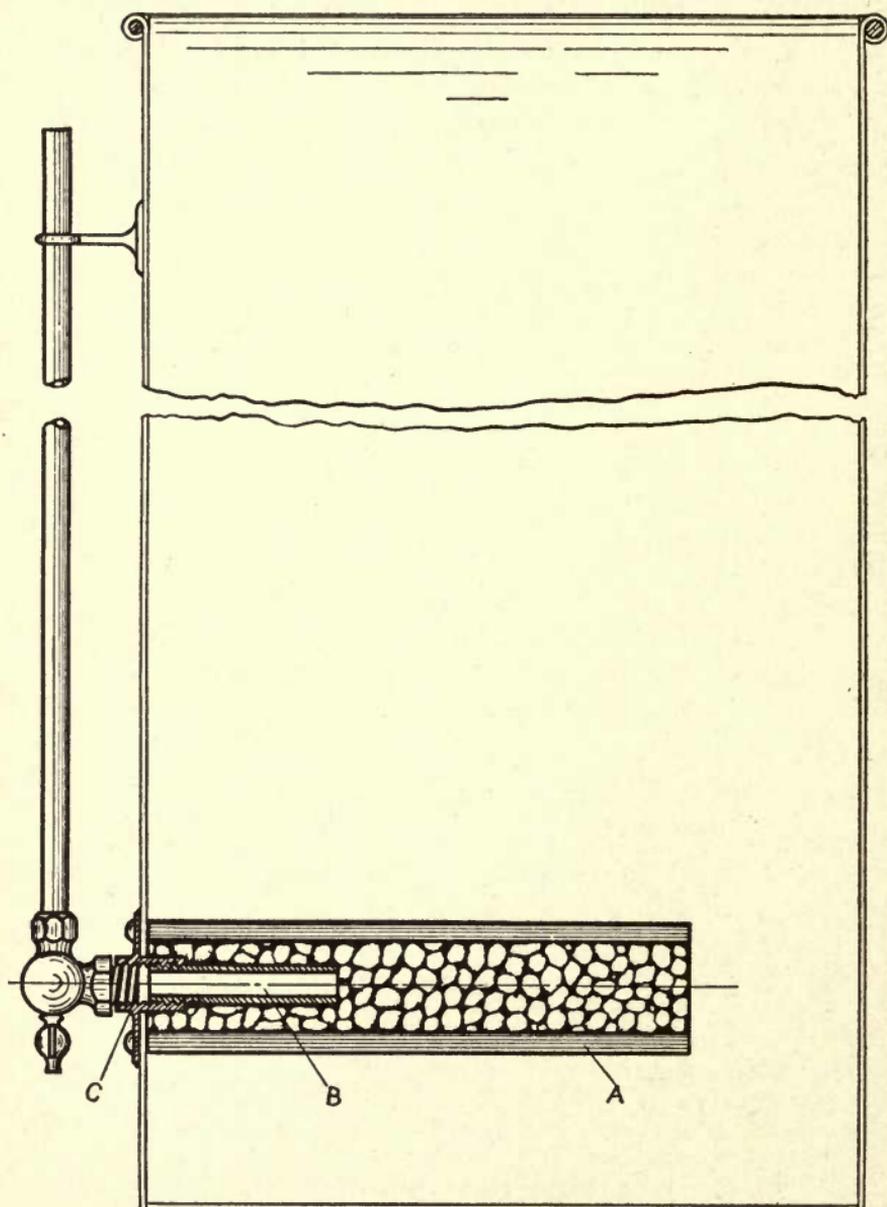


FIG. 95. — Detailed cross section of Fig. 93, showing the construction for permitting water to enter water gauge. See description, page 240.

EXPERIMENT 13

The Capacity of Tile of Different Sizes and Material to Remove Water by Percolation through the Tile Walls

1. Introduce water into the tank till the surface stands 1 inch deep over the sand, and allow to stand some hours (unless the sand be already saturated to some inches above the level of the tile).

2. Place vessels under faucets.

3. Open faucets and permit water to flow till flow becomes constant for each faucet.

4. Place an empty vessel under each faucet and record time.

5. After an hour (more or less, as the rate of flow may require), close faucets or remove vessels. If the vessels are placed in position and removed in the same order, the time of the series will be sufficiently close.

6. By weighing or measuring, determine the amount of flow for each tile.

7. Compute flow to the acre for each size of tile, assuming the tile drains to be placed 4 rods apart.

EXPERIMENT 14

The Relation of Diameter of Tile to Rate of Flow of Water through Walls

With data obtained in Experiment 13, determine whether there is a relation between the diameter of tile and the rate of flow through its walls. This experiment assumes that two or more sizes of the same make of tile are used in the apparatus.

EXPERIMENT 15

Relation of Richness and Mix of Cement Tile to Rate of Flow of Water through Walls

From the data obtained in Experiment 13, determine the relation of flow of water through the walls:

- (a) Of lean dry-mix tile as against rich wet-mix tile,
- (b) Of cement tile as against common clay tile.

EXPERIMENT 16

The Position of Water-Table in Tiled Soils

1. By filling or removal (by opening faucets), bring the surface of water to the surface of the sand.
2. Close all faucets and allow to stand sufficiently long for the water to come to equilibrium in the sand.
3. Measure and record height of water in water gauges.
4. Open faucet No. 1 and permit the water to run.
5. At the end of every five minutes, while the water is flowing from faucet No. 1, measure the height of water in water gauges. Ten-minute periods may be better. If time permits, continue these readings until water ceases to flow from faucet. There should be a student for each gauge, in order that the readings for each period may be made simultaneously.
6. Plot height of water so that curves shall appear on chart for each set of readings of water gauges.

EXPERIMENT 17

Influence of One Inch of Rainfall on Height of Ground Water-Table

1. See that faucets are closed and that water in gauges stands not much over 6 inches above the level of faucets.
2. Measure and record height of water in gauges.
3. Determine the cross section of tank. It will approximate 60 inches by 15 inches.
4. Introduce into the tank an amount of water that equals one inch over the cross section of the tank. This will be approximately 900 cubic inches of water.
5. After water has come to constant height in all the gauges, measure and record height of water in each gauge.
6. With the data thus obtained, determine the influence of an inch of rainfall upon the height of ground water-table in this particular soil.

EXPERIMENT 18

Percentage of Pore Space

With the data obtained in Experiment 17, determine the percentage of pore space in the soil in the tank.

PRACTICAL EXERCISES

In addition to the laboratory exercises outlined above, the student should be made familiar, by practice, with the several operations involved in the use of the level, laying out of drains, and, when possible, with the actual work of digging drains and laying tile. These operations may be grouped something as follows:

1. *The use of the level.* Setting up; taking and recording readings; determining height of instrument; determining difference in elevation of two points.

2. *Laying out a drain.* Establishing location; driving grade stakes; placing finders.

3. *Notes.* Making tables; introducing stake numbers; distances; and elevation of stake 1.

4. *Leveling.* Taking back-sight and fore-sight readings, and properly recording.

5. *Computations.* Determining the elevations of the grade stakes; making profile; establishing grade; determining depth of ditch at each grade stake; determining the height of grade bar at each grade stake.

6. *Setting up grade bars.*

7. *Digging ditch* (when a practice ditch, or better where a real ditch, can be had to dig). Opening ditch; digging ditch; finishing bottom.

8. *Laying tile and blinding.*

9. *Filling.*

10. *Construction of hose-level and rods.*

11. *Use of the hose-level.* Leveling with rods; leveling without rods; making computations, if opportunity offers, to establish grade, and determine depth of ditch and height of grade bars for a drain.

These operations are fully explained in the text and may be taken up as the text is studied or they may follow later.

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