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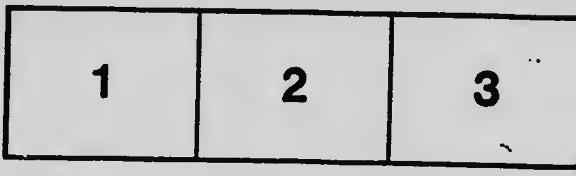
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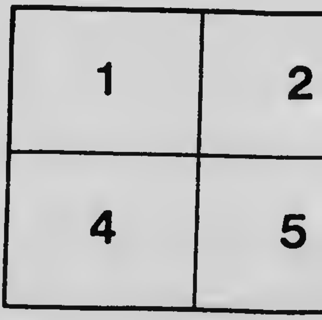
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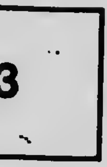

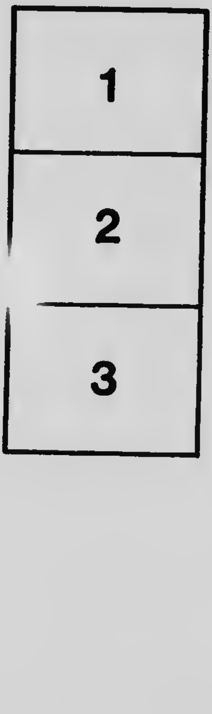

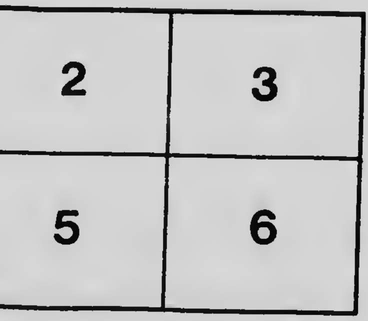

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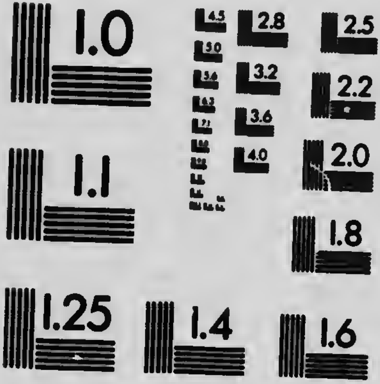

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Ontario Department of Agriculture.

ONTARIO AGRICULTURAL COLLEGE.

PRINCIPLES OF TILLAGE AND ROTATION.

BY WM. H. DAY, B.A., LECTURER IN PHYSICS.

It is the chief purpose of tillage to improve the condition of the soil in order that it may the better minister to the plant, which needs moisture, air, warmth, food, and proper sanitary environment.

Perhaps the most important factor in crop production is the proper supply of moisture, for on this depend all the others. If the water is excessive, the soil is cold, and germination and growth slow, air cannot reach the roots, and the plant suffocates, grows sickly, and refuses to assimilate the food. If, on the other hand, the water is insufficient, no amount of air, warmth or food can avail to produce a crop. Hence we shall notice first, tillage in relation to soil moisture.

It may be well at this juncture to inquire, "Whence do crops draw their supply of moisture? Do they draw it mainly from the rains that fall throughout the growing season, or do they draw it rather from the store of water in the soil beneath, accumulated there from the April showers, the snows of winter, and the rains of autumn?" This is a vital point, on it hangs the whole question of cultivation. If the supply is drawn mainly from the summer rains, then our cultivation must be such that the soil will absorb quickly the water of those summer rains, and rid itself quickly of the surplus; if it is drawn mainly from the spring, winter and autumn precipitation, then our cultivation must be varied accordingly. Whether they draw from the summer or winter precipitation, depends to a certain extent upon the season. During a very wet season plants feed largely upon current rains, but during a moderate or dry season they have to draw from the store below, because the evaporation from the soil and the transpiration by the plant exceed the amount of rainfall while the plants are growing. Let me give you here the result of a little test we have made on this point. Last year was a rather dry season. We sowed wheat, peas, barley, and oats in four-gallon crocks, and set them outside where they received all the rain that fell during their period of growth, but this was found insufficient, and the crocks were watered at intervals as necessary. The results were as follows:—

Table Showing Rainfall and Depth of Water in inches used by Crops during a Dry Season.

Crop.	Depth of rain while crop was growing.	Depth of water added.	Total depth of water used by crops.	Total depth compared with rainfall.
Wheat	10.51	12.09	22.60	2.15
Peas...........	12.50	14.88	27.38	2.19
Barley.........	7.91	10.61	18.52	2.25
Oats...........	7.91	13.24	21.15	2.57

That is, these crops, during their period of growth, used approximately two and one-quarter times as much water as fell in rain. Since the plants did not grow as large or strong as those in actual field conditions, we are safe in assuming that field crops used as much as or even more than those in the crocks. Last season was about an average one. Thus we see that under ordinary conditions, if the crops are to be supplied with all the water they need, there must be a great store of it in the soil from which they may draw. Hence, in anticipation of an average or dry season, our treatment of the soil must put it in such a condition that it will retain a great deal of the spring, winter and autumn precipitation. The crocks in 1905 were set on the roof of the annex to our building during the early part of the season; but it was thought that possibly the loss there was very much in excess of what it would be at the ground. So about the middle of the season half the crocks were removed to the garden, part being set on the ground and part in the ground about level with it. Between the losses from the former and the latter, the scales showed no difference, though the loss from those on the roof was slightly greater than from those in the garden. But the first tests in any experiment are seldom made in just the same wa[illegible]equent ones. This season (1906) all crocks were set in the g[illegible] a field of barley, a path leading into the grain, and the crocks [illegible] back in it on either side of the path.

The crocks had a capacity of four gallons, were 10 inches in diameter, and about 12 or 13 inches deep, and caught all the rain that fell. The day they were set outside a very heavy rain fell, and having weighed them just before the rain, we weighed them again just after, and compared the result with our rain-gauge. It was found that the crocks had absorbed the whole shower. None of the rain was lost by drainage. We had a drainage tube in the bottom of each crock, but not once during the whole season was the rain sufficient to saturate the soil and cause percolation. The quantity of rain required to saturate the soil depends on the amount of moisture in the soil when the rain comes. We tested that point once during the season. We let the soil dry out until the grain began to wilt. The amount of water in the soil at wilting point varies in different soils. This was a loam, and by actual test was found to contain 7.3 per cent. water when the plants wilted. Water was added to the crocks until it began to run out of the drainage tube. When percolation had just ceased, they were weighed again, and it was found that to saturate the soil, which was nine inches deep, it required two and one-half inches of water. That is, in time of drouth, when your crops begin to wilt, it would require a rain of two and a half inches to saturate the soil nine inches deep. That explains why it takes so much rain to "break the drouth." In all our records here, we have no such rain in 24 hours. Only two or three times have we had as much as two inches. A rain of one and one-quarter inches would *saturate* the soil four and one-half inches deep, but gravity and capillarity would carry part of the water farther down, so that such a rain, which would still be a heavy one, would *moisten* the soil probably eight or ten inches. Since the soil is seldom so dry as to be at the wilting point, but generally contains from 15 to 20 per cent. of water and sometimes more, a rain of about one inch is often sufficient to cause percolation. A saturated loam contains about 30 to 35 per cent. water, by weight.

The season of 1906 was a very wet one during the growing time, and the same test resulted as follows:—

Table showing Rainfall and Depth of Water used by Crops during a Wet Season.

Crop.	Depth of rain while crop was growing.	Depth lost by drainage.	Depth of water added.	Net depth of water used by crops.	Total depth compared with rainfall.
Wheat ...	12.62	1.00	5.00	17.32	1.38
Peas	12.62	1.00	6.00	18.32	1.45
Barley ...	12.62	1.00	6.50	18.82	1.49
Oats......	12.62	1.00	6.25	18.47	1.47

Thus we see that during a wet season the crops do not use as much water as during a dry one, only about 18 or 19 inches in 1906, as compared with 23 or 24 inches in 1905, although the supply was much more abundant. Still they used about one-half more than the rainfall; but any soil, whatever its condition, retains enough of the spring and winter precipitation to supply this deficiency. The table also shows that part of the rain was carried away in drainage. In actual field conditions the amount to be thus removed would be much greater. Moreover, it is a matter of common observation that excessive water standing in the soil for 48 hours or more is very injurious to plant life. Hence, during a wet season it is our chief concern to remove the surplus water before its presence becomes dangerous to the crops.

Now it is a curious coincidence, or shall I say a provision of nature, that in most soils the conditions which, in a dry season, make for the retention of great stores of the winter and spring precipitation, and the subsequent conservation thereof, are the very conditions that in a wet season rid the soil most quickly of the surplus water. It behooves us, then, to inquire what these conditions are. First and foremost a proper soil texture, a granular condition not too fine nor too coarse, neither too compact nor too loose. Let me illustrate this by a simple experiment. Here are two brass tubes with sieve bottoms. Equal weights of loam were placed in them. In tube No. 1 the soil was packed to field conditions; in tube No. 2 it was left as loose and open as possible. Water was poured carefully into each and allowed to soak through. When both soils were just filled with water, the loose one *contained* 34 per cent. more than the compact. In soil six inches deep this is equivalent to one inch of rain, *i.e.*, if a loam is loosened up for a depth of six inches it will absorb one inch more than the compact soil before any of the water is lost by surface run off. The tubes were then let drain, and when all drainage had ceased, it was found that the loose had *retained* 28 per cent. more water than the compact, which amounts to four-fifths of an inch in six inches of soil. This is equivalent to a very heavy rain. A further test was made with these two samples. We measured the rate of drainage, and it was found that the loose soil allowed water to pass through it more than twice as fast as the compact did.

This illustration demonstrates one of the chief objects in fall-plowing, viz., the absorption and retention of water; it also teaches that deep plowing will achieve this object better than shallow plowing, and further that subsoiling may be beneficial, provided, of course, that the subsoil is left in the bottom of the furrow, as demanded by other conditions. It should be said here, however, that there are some soils, *e.g.*, light sandy loam, which do not admit of loosening up to any great extent, for being of coarse texture they dry out very rapidly when loosened up. We may infer also that lands with open subsoils (not too open, of course,) will have greater reserve of water for the plants in time of drouth than will those with close subsoils. And we might hence inquire if there is any means of improving the texture of subsoils of the latter class. In this connection, we recall that it is a matter of common experience that well drained soils will withstand a drouth better than similar soils not so well drained, although the crops on both might look equally well at the commencement of the drouth. This result, which, at first thought, might not be expected, finds its explanation in the fact that drainage always improves the texture of all the soil affected, subsoil as well as surface soil, and with improved texture the water-retaining capacity is increased. Thus, when the soil is in best condition for supplying water to the crops in a dry season, it is likewise most capable of protecting them during a wet one.

But there is another aspect of soil moisture that during seasons of average or scant rainfall is equally as important as that already considered, viz., the conservation of the water after it has been stored in the soil. The one great source of loss is evaporation. Few, I believe, have any conception of how much water may be lost in this way. We have had the good fortune to devise a reliable apparatus for measuring the amount of evaporation from water surfaces, and have been making continuous tests since the middle of May, and I must confess that we have been surprised at the results. The College reservoir, which you have all seen, is approximately 100 feet by 60 feet and 12 feet deep. How much water do you suppose evaporates from that reservoir per day, on an average, from May to October? Most people guess in gallons, and when we suggest barrels they look incredulous; yet it is a fact that on an average during that whole period 20 barrels a day were lost by evaporation, a depth of one-fifth of an inch. The greatest loss on any one day was 50 barrels, which occurred between 6 o'clock on the evening of August 24th and 6 o'clock on the evening of August 25th. The three days preceding had been excessively warm, but about 4 o'clock on the 24th the temperature dropped suddenly, and a very strong wind rose which continued throughout the night and the following day.

In measuring the evaporation we use a graduated glass standpipe of water which feeds automatically into an evaporating cup so arranged that the wind cannot blow the water out although the evaporating surface is level with the top of the cup. The amount that has passed out of the standpipe gives the *depth of water evaporated* since last observation, and from this we can calculate the amount in barrels. When we have another season's work on this and on evaporation from soils, we hope to publish a detailed report of our methods and our results.

An evaporation of 20 barrels a day from an area 100 feet by 60 feet is equal to about 140 barrels per acre. The amount will, of course, vary with the situation, exposure, temperature, etc. What the exact loss from soils would be during that period, we are not yet in a position to say, that problem lies all before us; but, from preliminary tests, we have reason to believe that so long as the soil is *bare* and *looks moist on the surface*, evaporation is robbing it of its moisture about as fast as it takes water from the reservoir. But as soon as the soil looks dry, or is hidden by a crop, the rate of evaporation falls off very rapidly.

These latter conditions are best brought about by cultivating and seeding as soon as the land is dry enough. If there are two plots of soil side by side, and one is cultivated and the other is not, the evaporation from the cultivated one is much greater for a day or so than from the other, but *this evaporation takes place chiefly from the loosened portion*, and hence in a very short time, provided no rain falls, this layer becomes dry and acts as a blanket to protect the soil below, diminishing the evaporation in one test we made by 62.5 per cent. Hence it is a matter of vital importance that the soil should be cultivated at the *earliest possible moment*. A delay of one week in this operation after the soil is fit will rob the soil of from one to two inches of water, an amount sufficient to tide the crop over the critical period of a drouth. Deep cultivation is not advisable, for all of the loosened layer dries out in time of dry weather, and since the deep blanket is little, if any, more effective than the thinner one, the extra loss from the thicker blanket itself is not atoned for by greater saving of water in lower layers, and is therefore a net loss to the plant.

With cereals the conservation of moisture by cultivation may be continued until the grain is nicely up. If a rain has come, packing down the soil and destroying the loose blanket and thus setting up rapid evaporation again, it is good practice to run over the crop with [illegible] harrow and restore the blanket. The saving in moisture will m[illegible] atone for any injury the harrow may do the young plants. With roots and other hoe-crops conservation of moisture may be continued throughout the whole season. Theoretically, they should be scuffled or cultivated after every heavy rain. This frequent working may not be always possible, but it should be followed as closely as practicable.

In humid sections, where the autumn rain is usually sufficient to saturate the soil, after-harvest conservation of moisture is not essential, and the customary ganging serves to sprout the weed seeds and also, together with the fall plowing, to put the soil in condition to retain enough water for the ensuing crop. But in sub-humid or semi-arid regions the tillage right after harvest is essential for the purpose of conserving moisture, as well as for the reasons already given.

Before leaving the question of soil moisture, I should like to refer briefly to the work in drainage that is being done by the department of Physics. Throughout the Province there are thousands of acres non-productive, or under-productive, at least, which, if drained, would be the very best of land. People are realizing this more and more, and drainage operations are being more generally undertaken than heretofore. But in many cases men are hesitating because they are not sure as to the best methods of going about it, whether they have fall enough, the best course for the drains, etc. The department of Physics is endeavoring to help these men. Anyone having such difficulties may have the assistance of a man from our department to take the levels of his land, determine the falls, locate the drains, give him a working plan of his farm or field, and advise him generally as to the best methods of operation. The condition upon which this service is rendered is that those wishing work done pay the railway fare, etc., of the person sent by us. When the applicant lives a considerable distance from Guelph, he sometimes clubs together with one or two of his neighbors who have work to be done, each paying a share of the expenses.

We have done a great deal of this work during the past season, and the men for whom we have done it express themselves very strongly on the benefits derived. I mention it here because of its connection with the subject in hand, and also in the hope of making the scheme more widely known. For the initiation of the plan, I wish to give due credit to Professor Reynolds, my predecessor in the department.

Another important soil factor is proper temperature. There is a certain temperature at which each kind of seed germinates best. Of the more common cereals, wheat has the lowest germinating temperature at about 70°, barley, oats and peas probably in the order named, at about 80°. This may throw some light upon a result obtained by the Experimental department. By several years' tests they have shown that the order in which these grains should be sowed is, first wheat, second barley, third oats, and lastly peas. And in testing six different dates of seeding at intervals of one week, they have shown that for wheat and barley the first sowing is the best, but for oats and peas the second. Temperature is undoubtedly one of the factors producing this result. This question and that of soil moisture are very intimately related. A wet soil is a cold soil, but a dry one is a warm one. The seed bed of a well drained, well tilled soil will be from 5° to 15° warmer than that of a poorly drained, poorly tilled one. The reason for this is found in two facts: (1) The behavior of different substances toward heat. It is more difficult to raise one pound of water one degree in temperature than one pound of any other substance in the soil. The same heat would warm dry sand 10°, dry clay 7°, dry loam 7°, dry muck or humus 5°, would warm the same weight of water only 1°. This may easily be proven. Take a pound of water and a pound of sand at the same temperature. Heat the sand 11° and put it in the water. The temperature of the water will rise 1°, the temperature of the sand fall 10°. Again, take two samples of the same soil, one saturated, that is, holding all the water it can, the other half saurated. The heat that will raise saturated loam 3° will raise half saturated loam 4.5°; and, by the way, a half saturated soil is in about the best condition for tillage, for germination, and for plant growth. Hence, from a temperature standpoint, you can see how essential it is that the soil should not be too wet. (2) Evaporation cools the soil. That this is so I can prove to you in this simple way. Here are two thermometers. They both read 67°. Here is a wet linen sack that just fits the bulb. One would think it should be the same temperature as the thermometers, for all have been lying here side by side. I slip the wet sack on one thermometer and watch the result. The wet bulb reads 59°, *i.e.*, 8° lower than the dry bulb. These readings would vary for different conditions. The only possible cause for this phenomenon is the evaporation from the gauze. The heat from the thermometer is going into the gauze and into the water and evaporating the water. You may take a certain amount of water and heat it from freezing point to boiling point. You cannot make the water any hotter, yet the flame is sending more heat into it all the time. What is becoming of that heat? It is being used to turn the water into vapor, or steam, as we say. It takes 5.35 times as much heat to turn water into vapor as it does to heat it from freezing to boiling. In evaporation the same thing is true, only, since there is no fire to supply the heat, it must come from the water itself, and hence the water is colder than the surrounding air. The very same phenomenon occurs wherever evaporation takes place. Hence, the sooner you get that dry blanket of soil on the surface and check the evaporation, the sooner will that soil become warm and suitable for seed-germination and plant growth.

A third soil factor in crop production is the proper supply of air. Whether the roots actually breathe this air as the leaves do has never been decided, but the fact remains that they can no more do without it than the leaves can. But absolute exclusion of fresh air occurs only when the soil is filled with water. Soils in a good state of cultivation permit sufficient change of air for all our crops but the legumes. We have been testing this point both last year and this year, and that is the conclusion we have arrived at. Peas, beans, clover, cow peas, vetches, etc., would all be benefited by more air than reaches the roots under ordinary conditions. This may explain why peas do so well on sod: the soil is open in texture and allows much interchange of air.

Perhaps it may be interesting to note some of the agencies that promote aeration. First, there is change of temperature of the soil. The air in the soil expands as it is heated, and thus some of it is driven into the atmosphere. If the rise in temperature amounts to 10° when the temperature of the soil stands at 45°, then one-fiftieth of the air in the heated zone is expelled; and if it amounts to 20°, then one-twenty-fifth is expelled, and so on. The change of atmospheric pressure also aids. If the pressure falls half an inch, the air expands and about one-sixtieth of it escapes; if the pressure falls one inch, one-thirtieth escapes. Rain is a very potent factor. As the water sinks into the ground, an equal volume of air must be displaced. As it passes away, by drainage, by evaporation, or by absorption into the plant, the air is drawn into the soil again. Drainage aids very materially. When rain falls on undrained land, the imprisoned air must escape upward through the water as the water sinks down; the two actions thus opposing one another, the air escapes very slowly, often so slowly that large quantities of water, being unable to make their way into the soil, run off the surface and are lost. But if the soil is well drained some of this run-off may be prevented, the imprisoned air escaping downward through the drains as the weight of water above increases, fresh air following the rain into the soil. This gives us another reason for the great superiority of the drained soil over the undrained. Proper tillage increases the efficiency of all these agencies of aeration.

Another factor, and one that is gaining some prominence at the present time, is a proper sanitary environment for the roots. The latest investigations of the Bureau of Agriculture at Washington arouse the suspicion that the apparent "exhaustion" of soils is not due so much to the depletion of the stock of plant food as to the lack of proper sanitary conditions. Animals forced to exist in an atmosphere rendered foul by their own poisonous exhalations soon cease to thrive; the plant above ground likewise gives up waste products, which if not removed, become a menace to its safety; is it not therefore natural to expect that from the roots of the plant also there are excreta that, if allowed to accumulate, threaten its very existence? As proper ventilation is necessary to insure the health of the animal, as diffusion, drafts and winds must bring fresh air to the leaves, so must tillage or other treatment purge the soil of the injurious substances cast off by the roots. In this purifying process it is believed that air, and therefore cultivation and drainage, plays an important part, certain fertilizer ingredients are effective under certain conditions, but more potent still is organic matter in the form of humus. There is another method, however, of eliminating the toxic or poisonous effects of these excreta. Whatever they may be, it appears that those cast off by one variety of plant are not, as a rule, injurious to another variety, hence the possibility of rotation of crops. By the time the first crop comes round again, the intervening cultivations having stirred up the soil, exposed it to the weathering processes, allowed the air to enter in and permitted the humus to do its work, all the excretions injurious to that crop have been removed or neutralized and we secure a yield equal to the last one. Hence it is that by proper rotation we may go on cropping our fields from year to year, cropping them indefinitely, without any apparent exhaustion, and indeed by wise rotation even increasing the yield.