"I mow and I plant
I plant and I mow,
While the sun burns hot on the plain.

I sow and I reap
I reap and I sow
And I gather the wind and the grain."

"The Farmer"—L. H. Bailey

The Farm Library

SOILS

How to Handle and Improve Them

By S. W. FLETCHER
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Illustrated from photographs
by the author

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Perhaps the most valuable feature of the book is the lists of crop rotations in the Appendix, which were contributed by authorities on this subject in the several states, as noted in connection with the lists. These courtesies are gratefully acknowledged.

THE INFLUENCE OF

John W. Spencer, Farmer

HAS GIVEN GREATER SIMPLICITY AND FORCE
TO AGRICULTURAL TEACHING

FOREWORD

Many of the early books on farming were written in a technical style. They smacked of the lecture room and the library rather than of the soil. They were scholarly rather than practical. A spirit of directness and simplicity is beginning to dominate agricultural literature. The modern type of farm books is born of actual contact with the soil and a desire to be of service to the men who are getting a living from the soil. They are democratic; they discuss common things in a plain way. The long and tedious tables of figures in the old books are giving place to crisp summaries. The technical lecture-room phrases are replaced by words in common use on farms. The idea is not to present less science—for nothing is so practical as sound science—but to present science in a simple and practical way. This new spirit is contemporaneous with the farmers' institute, the farmer's reading-course, Nature-study, elementary agriculture in the public schools and other efforts to serve the man who tills the soil. It is an expression of a general movement which aims to democracise agricultural teaching.

This book is an attempt to set forth the important facts about the soil in a plain and untechnical manner. It is not a contribution to agricultural science, but an interpretation of it—a new presentation of what is already known.

S. W. Fletcher.

Agricultural College, Michigan,
October 30, 1906.

CONTENTS

Chapter I. SOIL BUILDERS

Chapter II. THE NATURE OF SOILS

CHAPTER III. THE KINDS OF SOILS AND HOW TO MANAGE THEM

Chapter IV. SOIL WATER

Chapter V. THE BENEFITS OF TILLAGE

Chapter VI. THE OBJECTS AND METHODS OF PLOWING

Chapter IX. THE DRAINAGE OF FARM SOILS

Chapter X. FARM IRRIGATION

CHAPTER XI. MAINTAINING THE FERTILITY OF THE SOIL

Chapter XIII. FARM MANURES

Chapter XIV. COMMERCIAL FERTILISERS

APPENDIX

LIST OF ILLUSTRATIONS

SOILS

HOW TO HANDLE AND IMPROVE THEM

CHAPTER I

SOIL BUILDERS

MANY people who till the soil, either as a business or as a recreation, look upon it merely as dirt—cold, inert, lifeless, changeless. I have met farmers in New England who took it for granted that the land they till to-day is about the same as it was two hundred years ago, when their forefathers cleared it, except for being less fertile. They had not noticed, or at least had not interpreted, the soil-building and soil-changing agencies at work all about them—wearing away the uplands, enriching the meadows, reducing the rocks, filling the swamps; changing from year to year the contour of their farms and their agricultural value.

THE WEATHERING OF ROCKS

Every farm soil is a complex material and has an interesting history. Most soils are a mixture of ground rock, decayed plants and the remains of insects and animals. Some soils, as the sands, are almost entirely particles of rocks; others, as peat and muck land, are made almost entirely of decayed plants. Neither of these extremes makes a a good farm soil, as a rule. The majority of the soils in which plants are cultivated are made mostly of ground rock, with the addition of a greater or less amount of decayed plants.

Rock has been, and is still being, ground by weathering—the action of air, rain, snow, frost, heat and ice. Ever since the surface of the earth cooled, making a crust of rock, these agencies have been constantly at work, breaking up this crust, wearing away fragments of rock and carrying them to lower levels. They are Nature's plows. All mountains and hills are slowly wearing away. We can no longer regard them as "firm and everlasting." "Whole mountain chains of geologic yesterday have disappeared from view," says Merrill, "and we read their history only in their ruins." The Appalachian Mountains have already lost by weathering and erosion as much material as now remains. Even within the memory of one man, a hill may become noticeably lower.

The whole earth is being levelled—very slowly, yet quite perceptibly. The face of every rock is roughened and chipped by the elements. Drops of rain wear away particles of it; water freezes in the crevices, expands, and chips off fragments. The air searches these crevices and corrodes them, as it does iron. Everywhere cliffs are lower, rocks are smaller and soils are finer than they used to be. The big rock that the farmer has plowed around for thirty years is smaller now than it was when he first "rode horse" for his father. The stones on the gravelly knoll pass between the cultivator teeth easier than they used to. All about us, in the wild and on the farm, are indisputable evidences that soil is being made by the weathering of rocks. Most farm soils are still incomplete—they contain rocks and stones that are slowly being made into soil. A few, as the clays and alluvial soils, are changing less; but even the finest clay soil is affected by weathering to some extent. The reducing and fining process is universal and ceaseless.

1. TAUGHANNOCK FALLS, ITHACA, N. Y.
How many centuries has it taken this stream to wear the deep gap in the cliff ?

2. SOIL AND STONES BROUGHT DOWN BY STREAM
Much of it was worn away from rocks and cliffs like the above. Some day it will be used for farming

3. ROCK SPLIT BY THE GROWTH OF A TREE, WHICH HAPPENED TO FIND LODGMENT IN A CREVICE

"Half-way stone," Lansing, Michigan

4. LEDGE BEING TORN APART BY THE GROWTH OF TREE ROOTS IN THE CREVICES

Plants aid in soil building by the pressure of growth of stem or root

An interesting example of soil formation by weathering is the heaving of stones to the surface, especially in the clay soils of northern states. A vivid recollection of my boyhood is the thankless task of picking up stones from rocky New England fields. This had to be done every fall and every spring. Though we might pick up and cart off in the fall every stone to be seen, there would always be many on top of the ground by the time for spring plowing.

These stones were heaved up. The clay soil in which they were embedded became wet, froze and expanded, throwing the stones upon the surface, there being the least resistance in that direction. So many of our small fields of a few acres had immense piles of stones in each of the four corners, the accumulation of many years. When these stones are not picked up they lie upon the surface and are slowly reduced to soil.

Soil Becoming Rock.—The reverse process, of changing soil into rocks, is also taking place. Many of the common rocks and stones that we may pick up in our fields were once soil. Sandstone, which is now sought for trimming buildings, is sand that has been hardened into stone. "Pudding" stones, or conglomerates, are made of gravel. Sometimes these rocks may be broken up, by weathering or erosion, and the soil in them again become available for plant growth. Thus the materials of the earth's surface may be worked over and over during countless cycles of time. The soil that nourishes plants to-day may be the building stones of a future generation. The soil of every farm has an antiquity of no ordinary character.

Extreme Changes in Temperature Crack Rocks.—Weathering from changes in temperature is as effective, though often not as noticeable, as weathering from other causes. The changes of temperature from summer to winter, and even from the heat of mid-day to evening, are sufficient to tear rocks to pieces. Rocks are made of several or many different minerals, each of which expands and contracts differently when subjected to heat or cold. The result is that the rocks are cracked and split from being pulled many ways. There are few parts of the world where surface temperatures are uniform for any length of time; hence nearly all surface rocks, even the smallest stones, and especially those in the North, are being slowly pushed and pulled to pieces by alternate expansion and contraction. According to Shaler, a change of temperature of 150° F., which is common in the North between the extremes of summer and winter, makes a granite rock 100 feet in diameter expand one inch.

In regions having great extremes of temperature daily, particularly in Texas, Montana, Arizona, and other parts of the West where rocks are sparsely protected by vegetation, the splitting of rocks is quite noticeable and is sometimes attended with gun-like reports and cracking sounds loud enough to be heard many rods. Livingstone states that in South Africa blocks of stone weighing 200 pounds are frequently split off during the night by the contraction due to the rapid fall of temperature. Many people have noticed how pieces are chipped off from the foundation stones of a building that has burned. In most parts of eastern United States, where the rocks are more or less protected by vegetation, the cracking of rocks from this cause is less noticeable; but it is certain that all rocks everywhere are being affected more or

5. EROSION OF A MOUNTAIN IN MONTANA

The soil made on the mountain by weathering has been mostly washed away to make the fertile valley below

6. NIAGARA FALLS, CANADIAN SIDE

The Falls are moving backward towards Lake Erie at the rate of 4 feet a year. The rock particles worn away by the cataract are deposited as soil many miles down stream

7. THE BEGINNING OF A SOIL 6,000 FEET HIGH, ON GRANDFATHER MOUNTAIN, NORTH CAROLINA

The mountains are being worn away and deposited in the valleys as soil

8. MOSSES AND OTHER HUMBLE PLANTS ON LEDGE

They will help prepare the way for the growth of higher plants less. The simile—"immovable as a rock," is not perfect. Even the rock, our common symbol of stability, is subject to the universal law of change; it is broken down, re-created and broken down again, over and over, while it fills its place in the working out of the Great Design.

PLANTS AS SOIL BUILDERS

Broken rock alone, however, does not make a fertile soil, as the farmer defines fertility. There are plants that thrive on bare rock, but the plants that are grown as farm crops are of a higher order and cannot rough it like this. A fertile soil—one that will grow large crops of the higher plants, either wild or cultivated—must contain a considerable amount of humus, which is chiefly decayed vegetation. A soil made of rock alone may contain all the mineral plant food that farm crops need, but it is apt to lack nitrogen and has not the right texture.

The Evolution of a Soil.—Nothing in nature is more interesting than the gradual evolution of a fertile soil from a barren rock, and nothing is more significant of the illimitable wisdom of the Creator. The history of soil building reads something like this: In the beginning is a lofty cliff, mute witness of the eruptions and disturbances through which the earth passed in cooling. It is bare and desolate. No living thing finds nourishment upon it. For centuries the storms beat against it; ice, rain and sudden changes in temperature pry off great boulders, which crash into the valleys. In the course of time there come to be upon these boulders, and upon the rocks and stones split off from them, lichens and other humble plants that are able to send their minute root structures into the crevices and live upon the slight substances that are formed on the surface by weathering, together with what they can get from the air. These lichens are very acid and are able to etch the rocks. They die and decay, leaving the beginning of a fertile soil in the crevices and upon the ledges. The growth of higher plants is thus made possible; perhaps the mosses gain a foothold. These in turn elaborate more of the rock for their own use and in turn die, enriching the soil with themselves. Now there is a pocket of soil upon the ledge which may be able to support such humble plants as ferns or saxifrage. Thus the process goes on from decade to decade and from century to century, the lower plants being succeeded by larger and more highly organised plants, as the rocks are made finer by weathering and are enriched by the decay of the plants that they nourish. Finally the soil can support mulleins, honeysuckles, or fir trees. Many years later it may be able to support a crop of corn, timothy, or apples. A fertile farm soil is the product of many agencies working through thousands of years.

How Plants are Making Soil To-day.—Plants are helping to make fertile soil to-day as they have for centuries. Each year the forest floor receives a fresh carpet of leaves, and the older generations of trees fall to the ground and slowly pass into mold. Each year the grass in the meadows and the weeds by the roadside add their substance to the soil from which they have sprung, thereby enabling it to nurture other and lustier plants in succeeding years. Lichens spread their thin substance over rocks, and mosses take up the battle where the lichens leave off, just as of old.

Swamp lands and meadows are the most conspicuous examples of soils built mostly of plants. Lakes, ponds, streams and swamps are being filled in, not only with soil washed from surrounding higher land, but also with plants. The little pond that I skated upon as a boy is reduced to a mere mudhole now; the lilies, sedges, reeds, cattails and other aquatic and semi-aquatic plants have encroached upon it from the edges year by year, until now hay is cut where I used to catch bullheads. Most of the rich valleys and meadows of northern United States were once water-courses or glacial lakes. The weedy water's edge of today may be a sphagnum bog a century hence and a cabbage field in another hundred years. The mangrove swamp of this century, reaching trunk-like roots into the sea, may be the tilled land of a future generation.

Stems and Roots Split Rocks.—Plants also aid in soil building, to a considerable extent, by the pressure they exert upon rocks. The roots of trees often follow the crevices of rocks to a considerable depth, and by the force of growth help to widen them. Even on top of the ground one may see many examples of rocks that have been rent by the growth of trees. Among greenhouse plants it is quite common to find pots that have been split apart by the growth of roots. But in many of the cases where rocks are split apart, and a tree is growing in the crevice, the rock was was first split open by weathering and the tree then widened the crevice. The acids secreted by the roots of plants dissolve a small portion of plant food from the rocks that the roots embrace. Rocks that have been etched by root acids may be found in almost any tree-covered ledge. In these various ways plants are contributing to the upbuilding of our agricultural soils.

The peculiar value of certain plants as soil binders must not be forgotten. One of the most efficient and certainly the most notorious of soil binders is "quack-grass," and its counterparts variously known as "Johnson-grass," "witch-grass," "couch-grass," and other aliases. The evil reputation of this grass is due to the fact that it is extremely difficult to kill, because the long underground stems may root at any point. The smaller the pieces into which the roots are chopped by the irate husbandman, the more widely and thoroughly is the pest scattered. This is just the reason why "quack" is such an excellent soil binder; the tough, white root-stalks thread the soil in every direction, soon making a network of fibres, which prevent light soils from washing badly. Steep banks or slopes are sometimes held by establishing quack grass upon them; the underground stems are chopped into small pieces and these are sown thickly. Several other grasses, notably Bermuda grass, are particularly serviceable in such cases.

In some sections, notably in Oregon, Eastern Massachusetts and Western Michigan, drifting sands are held by planting them with sedges or "beachgrass." In Holland the dikes are planted with rushes to bind the soil. Willows and osiers planted on the banks of turbulent streams are effectual in preventing them from eating away their banks. Morning-glories and related plants are called bind-weeds, because the vines root at the joints and hold the soil tenaciously. A few horsetails planted in a wet place soon make a dense mat of roots which grasp the soil so firmly that it cannot

9. A POND FILLING UP

Plants encroach upon it more every year until finally it is completely filled. Sometime this land may be used for farming

10. A POND COMPLETELY FILLED BY PLANTS

Ten years ago this was a sphagnum bog. The water-loving alders and viburnums around the edges will enlarge their area every year

11. THE HUMBLE BEGINNINGS OF A SOIL

Upon the pieces of rock chipped from the ledge several plants have gained a foothold. When they die their substance is added to the rocks and other plants thrive thereon

12. THE GREAT USEFULNESS OF PLANTS AS SOIL BUILDERS

Leaves, stems, roots—all parts of all plants—eventually return to the soil, adding to it and enriching it wash away. These are only a few examples of plants that are particularly valuable for this purpose. All plants are soil binders to some extent, as well as soil makers; they not only enrich it with their herbage, but also hold it with their roots and, if they lie close to the ground, with their herbage also. In hilly sections some plants may be used to great advantage in checking erosion. This problem is discussed in Chapter XI.

HOW ICE HAS MADE SOIL

Once the northern part of North America was covered with a great sheet of ice, reaching as far south as Cape Cod, northern Pennsylvania, Ohio and westward to the Rockies. Geologists tell us that this immense glacier must have been several hundreds, and in some places several thousands of feet thick. It slowly bore down from the north, moving only a few inches to a few feet an hour, scraping the surface of the earth and carrying great quantities of rocks, stones and soil to the southward. According to some authorities certain parts of the glacier must have exerted a pressure of at least two hundred thousand pounds per square inch upon parts of the surface over which it passed. The bottom of the ice sheet became studded with huge boulders, which acted like teeth, tearing and grinding the rocks over which the ponderous mass passed. Some of these boulders, scratched and worn, may be still seen in the hillside pastures of New England and other parts of the glaciated region. Some exposed ledges of rock still show the deep grooves that were cut in them by these boulder teeth.

When the ice melted a mass of soil material was dropped, perhaps many hundreds of miles away from the place where it was picked up. Rocks that could have come only from the mouth of Lake Huron are found in the drift or glacial soils in Ohio. Rocks from Ontario are found as far south as Kentucky. Great masses of ice were stranded here and there over the land. The streams of water resulting from the melting of the ice still further mixed the rocks, and the soils that the glacier had ground from the rocks.

The result of this ice sheet is the endless variety of soils that are found in the North. Most of the soils of that part of the northern United States that was covered by the great glacier were made by this agency. They are technically known as "drift" soils. Where parts of the ice sheet settled and melted away there were formed "morains" or "drumlins," the long, rounded knolls so common in northeastern United States. Since the time when this ice sheet covered our land, moving water has still further shifted and mixed soils, rounded the knolls and deepened the gullies. But most of the great variety of soil and diversity of contour in this region is due to the scouring, crushing, molding, transporting and distributing power of the great glacier. Small glaciers, performing exactly the same work, may be seen to-day in the Alps, Alaska, and other frigid regions.

ANIMALS AS SOIL BUILDERS

Animal life contributes much more to the building of soils than seems possible at first thought. Eventually every animal and insect returns to the soil, from which it came. The addition of animal matter to the soil is not nearly so evident as the

13. MANGROVE SWAMP IN FLORIDA

The branches take root, causing the plant to spread so rapidly that large areas of salt marsh land are reclaimed from the sea. Some day this land will be cropped

14. COCOANUT TREES ON THE COAST OF FLORIDA

They hold the soil and carry it farther out into the sea

15. CASTINGS OF EARTHWORMS ON SURFACE

Earthworms are a great benefit to soils, their burrows loosening and draining a soil and their castings making it finer

16. ANT-HILL

These insects bring to the surface a very large amount of fine soil—one-fifth inch a year in some places

17. PIECES OF ROCK SPLIT OFF BY FROST

Some day the pieces will become soil

18. LICHENS ON ROCK

They etch some material from the rock and when they die higher plants may gain a foothold addition of vegetable matter from decaying plants; yet, when we reflect upon it, the excrements and the remains of all creatures upon the earth must aggregate a considerable amount.

Of no small importance also, are the burrows, channels, holes, etc., in which animals live or by which they feed. Ants, moles, gophers, woodchucks, and the like are insignificant soil builders as individuals, but in the aggregate they have great influence. Ants are abundant on many of the lighter soils and often exercise a profound influence on their structure and agricultural value. Shaler has calculated that ants bring to the surface of a four-acre field, in Cambridge, Massachusetts, enough sand and fine soil to cover the entire area one-fifth inch deep each year. This is probably a larger amount of material than ants move in most places, although those of us who have had to fight ants in lawns are quite willing to accept these figures; but they call our attention to the insidious and far-reaching influence that these tiny creatures may exert. Since the material brought to the surface by the smaller ants is mostly fine sand and smaller particles of soil, they being unable to move the larger particles, it is evident that the texture of the surface soil must be greatly modified by their industry.

The mounds built by the large black and brown hill-building ants are often two feet in height and four feet in diameter. They are composed mostly of soil brought from below, mixed with bits of leaves and bark. They are being washed down constantly by rains and added to the surface soil. These ants usually build a new mound each year. Furthermore, the subterranean burrows and channels of ants, penetrating as they do from several inches to many feet, have a pronounced effect upon the texture of the soil, and upon its aëration.

The burying beetle, crayfish, woodchuck, chipmunk, mole, gopher, prairie dog, ground squirrel, badger, and other burrowing animals and insects, all contribute largely, in the aggregate, to the movement and aëration of soils, the latter four being especially abundant west of the Mississippi. Gophers have honeycombed millions of acres, and prairie dogs and ground squirrels have been no less industrious. However injurious these animals may be otherwise, and however difficult may be the task of exterminating them so that crops can be grown, they certainly serve a useful purpose in mixing the subsoil with the surface soil and promoting better drainage and aëration. Thousands of acres of land in the United States have been submerged by the erection of beaver dams and their value for agricultural purposes has been profoundly influenced thereby. The beaver is no longer an important factor in soil building with us, but he has contributed very largely in the past.

The Important Service of Angleworms.—The most important soil builder among animals is the angleworm or earthworm. Of these there are many kinds, from the big, snaky "night walker," that the fisherman with a torch finds crawling along the ground at night, to the tiny red ones beneath the pile of old manure. In South Africa some earthworms are two feet long. All of them are most industrious soil workers. After a rainy night, especially in early spring, the ground may be thickly strewn with their castings. On digging down in most moist soils a labyrinth of angleworm channels will be found. These burrows go more than five or six feet below the surface.

Angleworms benefit farm soils in several ways. The channels that they make loosen, aërate and drain the soil to a considerable depth, far deeper than the subsoil plow works. The small roots and rootlets that reach deep into the subsoil usually follow the worm burrows, This is particularly true of tenacious soils, in which angleworms most frequently work. They are rarely numerous in very light, sandy soils because these do not contain a sufficient quantity of vegetable matter upon which they may feed. Again, the soil is fined by being passed through the worms. In making these channels the worm swallows the soil for the purpose of using as food the decaying vegetable matter it contains. As it passes out through the worm this soil is ground, as grain is ground in a chicken's gizzard. Charles Darwin estimated that the angleworms in English soils passed through their bodies and ground over ten tons of soil per acre each year; that is, they deposited about one-fifth of an inch of castings over the entire surface each year. This is the richest kind of top-dressing. He estimated that there are about 50,000 earth worms in each acre of English garden land, and about 25,000 in each acre of meadow land. Our American soils are as full of "bait worms" as the English soils, and their influence on our agriculture must be fully as pronounced as that assigned to them by the great scientist.

THE ACTION OF MOVING WATER ON SOIL

No soil is ever at rest. It is constantly receiving and constantly losing. The additions come mostly from the weathering of rocks and the decay of plants and animals. The losses are mostly due to the action of moving water. Moving water has been given the gigantic task of world levelling, and is working at it industriously and successfully. The mountains, hills and knolls are worn away; water carries the particles down the valleys and deposits them as soil. Lakes and ponds are being filled with soil washed from higher land. The flat lands about the lakes and streams are made mostly of soil worn away from the surrounding highlands. The streams carry great quantities of soil and deposit it in the shallows and bends. The coarser and heavier materials. as gravel and sand, are deposited first and the finer material, as clay, is deposited only when the current becomes sluggish. At the mouths of streams, where the current is sluggish, a "delta" is often formed by the accumulation of soil carried down by the streams. It has been estimated that the amount of soil carried to the Gulf of Mexico every year by the Mississippi River would cover a square mile of territory 268 feet deep. At this rate, the American continent might be reduced to sea-level in four and one-half million years. This is but a small proportion, however, of the total amount of soil that these rivers carry, for most of it is left along their banks. According to reliable measurements, England is 550 square miles smaller now than at the time of the Norman Conquest, owing to the soft chalk and clay shores being crumbled away by waves.

Every stream is constantly changing its course; many a valley farmer has had the river take away a large slice of his farm and give it to his neighbour down stream. Brooks states that within a generation the Connecticut River has gradually taken several hundred acres of rich meadow land from the town of Hadley and bestowed it upon the town of Hatfield. Smaller streams, even the tiniest rills, are transporting and building soil in a similar manner. Sometimes this action of water is beneficial, but usually it is injurious. The loss of farm soil by erosion is discussed in Chapter XI.

Alluvial Soils.—The flat lands near streams are often flooded each year and receive a top-dressing of rich mud that keeps them extremely fertile. The Nile is a noted example, but many of our own rivers, including the Ohio and Mississippi, fertilise their meadows in the same way, much to the profit of man. The fertile plains of Egypt, once the "granary of the world," are not made of native soils, but of soil washed down from the mountains of Abyssinia, many hundreds of miles away. All the rich rice and cotton fields of southern Louisiana were built by the Mississippi River, of soil brought from the mountains three thousand miles away. In some places this soil is three hundred feet deep. These various kinds of alluvial or water-built soils are among the most valuable for agricultural purposes. In any hilly country one can observe this kind of soil building going on at a rapid rate.

Besides transporting soil from place to place, water also assists in soil building by wearing away the rock over which it passes. It would seem hardly possible that water should be capable of wearing away so rapidly the hardest of rocks, were it not that we can see the action going on all around us. Even a single drop, falling continuously year after year, will eat a deep hole in the hardest rock. When a volume of water is in motion, and especially when it is carrying along with it particles of soil, its grinding and filing effect is much more pronounced. The stones on the bottom of the brook at home are rounder and smaller now than when we first watched the tadpoles there. The spring that slaked our thirst twenty years ago has worn a deeper channel in the rock over which it flows. Each year the apex of the Horseshoe Falls of Niagara is four feet nearer Lake Erie. The Colorado River, which has already worn a channel half a mile deep in the solid rock of the Grand Cañon, is cutting deeper every year. All water, even the purest spring water, has some minerals and gases dissolved in it, and these help it to dissolve the rock. Rain water contains small quantities of carbonic acid gas and other gases, which increase its power to dissolve rocks.

SOILS BUILT WHOLLY OR PARTLY BY THE WIND

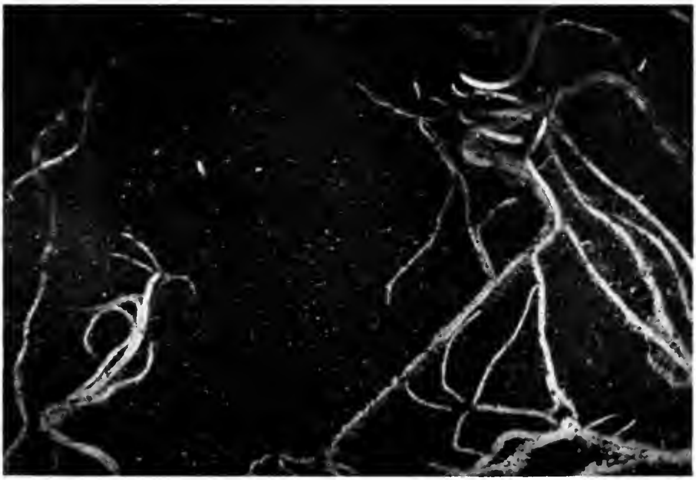
Soils built wholly or in part by wind are not uncommon. In arid regions, along the sea coast and near the shores of the Great Lakes, the drifting sands often cover and ruin valuable soils. Some of the most productive farm soils in this country were made, and are still being made, by wind. A noted example is the Palouse region of eastern Washington, eastern Oregon and northern Idaho. Here the land is a succession of rounded knolls and hills, which are sometimes several hundred feet high and are a rich, black, basaltic ash to the bottom. The native Indians account for the hills in a legend. They say that at one time all this region was a level prairie of marvellous fertility. Wonderful crops of maize were raised upon it by the red men. One evil day they heard that the white men were coming. Knowing by repute the white man's greed, the Indians went to work to gather the

19. HOW WATER MOVES THROUGH THE SOIL

It creeps from grain to grain by suction. The finer grained a soil is the higher it can pull up water by "capillary action." Compare the height to which the water in the pan has climbed in the clay soil on the left, with the coarse-grained sand on the right

20. THE DIFFERENCE BETWEEN THE SURFACE SOIL AND THE SUBSOIL

The former is usually darker, having more humus, and usually richer. The subsoil, however, is potential plant food; it gradually becomes surface soil



21. HOW PLANTS EAT

The fringe of delicate root hairs may be seen on many of these rootlets. The root hairs feed on the outside of particles of soil. Hence the finer a soil is the more feeding area it has precious soil into huge heaps, preparatory to carrying it away into the mountains, beyond the grasp of the avaricious whites. But the white men came before the soil could be carried away, took it for their grain fields, and it has been in heaps ever since. The more prosaic geologist, however, says that these fertile hills were made almost entirely by wind, assisted by erosion. In parts of California, Oregon, Washington, and Wyoming, the clayless "dust soil" becomes cracked and loosened in dry weather and is carried away by the wind in dense clouds, banking up like snow behind rocks and bushes. Recall, also, the stories of caravans in the desert being overwhelmed by sandstorms. There are numerous records of large quantities of soil being carried over a thousand miles by wind.

Even where the soil has been made mostly by other agencies, wind contributes something to it. Fine soil, leaves, chaff and dust are swept over the hill crest and deposited on the leeward slope. The amount of soil that is made and transported by wind, in the form of dust, must amount to an appreciable quantity in the course of a year. The slope opposite to that of the prevailing wind is usually less abrupt than the other, because so much soil material has been deposited there by the wind.

Still another way in which wind assists in making soil is by blowing fine particles of sharp sand and dust against the rocks and so wearing them away. At first thought it would seem that the result of this would be very insignificant, but in reality it is often quite important. In arid parts of the United States and elsewhere, the millions and millions of soil grains blown against cliffs and rocks leave a striking testimony to their abrasive power. In a surprisingly short time rough corners are worn smooth, great boulders are undermined, hollows are scoured out, and sometimes large, erect rocks are completely filed off near the base, where the wind-blown sand is thickest, and fall over. The "Mushroom Rocks" of Wyoming are a notable example. In humid sections, the filing of rocks by blown sand is less conspicuous, except near the sea-coast. The windows of houses near the coast are roughened and sometimes eaten through by the natural sandblast.

THE SOIL TEEMS WITH LIFE

There are other soil builders, more minute but not less active or influential than those that have been mentioned. The old idea was that the soil is dead; the fact is, it teems with life. It contains germs of decay, bacteria that influence in some mysterious way the palatability of plant foods, ferments of many kinds, moulds of diverse sorts—a fertile soil fairly hums with activity. Countless tiny organisms, visible only to the eye behind a microscope, are constantly at work, changing, breaking down, building up. Some are beneficial, some are harmful, some are harmless. How many kinds there are, and what part each plays in the complex operation of soil building, nobody knows, for the science of bacteriology is yet at its beginning.

Every farm presents many phases of soil building and soil wasting. The farmer should observe the various agencies at work upon his land, and turn them to his own profit. He should remember that the soil is not dead, but alive; that it is constantly

22. A SEDENTARY SOIL OF NORTH GEORGIA

It is made by the surface weathering of the underlying rock—the red shale here shown coming to the surface

23. A TRANSPORTED SOIL—THE "PALOUSE COUNTRY" OF OREGON AND WASHINGTON

It was laid down in these low hills mostly by wind. This soil often is several hundred feet deep and is very rich

24. AN ALLUVIAL OR WATER-MADE SOIL—THE MOCCASIN BEND OF THE TENNESSEE RIVER, FROM LOOKOUT MOUNTAIN, NEAR CHATTANOOGA, TENN.

There are several thousand acres below the "ankle." Sometime the river will cut through at that point. Alluvial soils are usually deep and rich

25. A SMALL BROOK DOING EXACTLY THE SAME WORK AS THE RIVER ABOVE

Note how it is cutting into the bank on one side, and building up soil on the other. Moving water is levelling the world swept by winds, worn and transported by waters, broken and refined by frost and air, loosened and enriched by plants and animals, and all the while creeping nearer and nearer to a level.

CHAPTER II

THE NATURE OF SOIL

IF WE take up a handful of mellow soil and look at it closely, we can see only a crumbling mass of particles, intermixed with black bits of decayed and decaying vegetation. There seems to be no life in it. Put a bit of this soil on a glass slide and look at it under a powerful microscope; a scene of constant activity is now revealed. Moulds, ferments, decays, bacteria, and other organisms are constantly at work, destroying, creating, changing the structure and the agricultural value of this soil. Currents of water pass through it; waves of heat quicken it. The tiny particles of rock are ground and worn smaller each year, and the plant foods are changed from one form to another. The soil has a flora and a fauna scarcely less complex than that which clings to its surface. Little is now known about the soil as compared with other agricultural subjects; it is remarkable that the soil, the foundation of agriculture and the beginning of all wealth, should have received so little minute study. We may expect the present deep interest in soil physics and soil bacteriology to greatly increase our knowledge of this most important factor in successful farming. Some of the significant facts about the nature of the soil, according to present knowledge, are considered in the following paragraphs.

THE FINENESS OF SOIL

It was stated in Chapter I that the basis of most farm soils is rock, ground into "rock-meal" by Nature's millstones, the air, water, frost, ice and other elemental forces. At first the soil particles are very large, mere fragments of rock at the base of a cliff, but upon these wild morning-glories or mulleins may be able to grow. Some hundreds of years later these small rocks will be finer; perhaps they will average less than one-quarter inch in diameter, and they will be mixed with humus. The fining process goes on a few generations or centuries more, until the pieces of rock have been broken into such small particles that farm crops thrive upon them. Nearly every soil is constantly becoming finer. All soils that contain small rocks or pebbles receive from them each year many particles of soil by weathering, and the size of the rocks and pebbles is reduced that much. Even the rich prairie loam or alluvial clay, which is apparently all soil and contains no rocks or pebbles at all, is becoming finer. Weathering is much less active on such soil, however, than on gravelly and stony soils.

The number of individual particles in a fertile soil is astonishing to those who have not tried to count them under a microscope. A good corn soil has about 280,000,000,000 particles in an ounce, while the clay loams that are preferred for grass often have 400,000,000,000 particles in an ounce. These particles are of varying sizes and shapes, even in the same soil. Sometimes they are uniform and rounded, and pack together poorly, leaving large spaces between them, like marbles piled together. Sometimes they are uneven and jagged, packing together tightly, like the crushed rock of a macadamized road.

The spaces between the soil particles differ in size and shape, according to the size and shape of the grains. I have met a farmer who could not quite see how a soil could contain air at a depth of four feet, yet he admitted that there must be air at the bottom of his wheat bin. The trouble was he looked upon the soil as a solid mass, since he could not see the spaces between the grains with his naked eye as he could in wheat. If he would think of his soil as a bin of wheat, with the kernels about one-millionth as large, he could see how it is that air and water pass freely through all ordinary soils, and to a great depth.

It is of practical as well as of scientific interest to know about the size of the grains of a soil, and the size of the spaces between them. The value of a soil for certain crops depends quite largely upon just such factors. With the refinement of soil surveys and methods, soil experts assure us that they will be able to tell us with a fair degree of certainty that soils containing, for example, from 250,000,000,000 to 350,000,000,000 particles per ounce are adapted for potatoes; soils containing 350,000,000,000 to 450,000,000,000, for onions, and so on. At present we classify soils and judge their adaptability for certain crops in grosser terms; we say potatoes do best on a sandy loam, and that an alluvial clay loam is excellent for onions. There are limits to the practical value of this information, for the fineness of the soil is but one of many factors that determine the adaptibility of a certain soil for a certain crop; yet this one point is extremely valuable to know when selecting land for special crop farming.

Fineness is Richness.—The fineness of the soil has a very important bearing upon its fertility. Other things being equal, the finer a soil is, the richer it is, because it contains more surface for the roots to feed upon. The rootlets of plants do not suck up particles of soil, as Jethro Tull supposed, in his now famous "Horse-hoeing Husbandry." They feed upon the film water upon the outside of the soil grains. This contains much plant food dissolved from the grains. The natural agencies that dissolve plant food from the soil—water, air, etc., act only on the outside of the particles. Hence the more surface there is to the grains, the greater is the "pasturage," or feeding area for the rootlets, and the more rapid is the weathering. If a small stone is broken into six pieces, the pieces have several times more surface, in the aggregate, than the unbroken stone. It has been calculated that if every particle in one cubic foot of mellow soil could have all its surface spread out flat, the aggregate surfaces of all these grains would cover about one acre.

The presence of small stones and pebbles in a soil is beneficial, making it lighter, more porous, and warmer. It would be a great calamity if all soils contained no pebbles and larger pieces of rocks. These are a store of plant food which is added to the soil from year to year. Yet the farmer should remember that, in general, fineness means richness. If a soil is lumpy, because of lack of humus or excessive moisture, its available feeding area is greatly reduced. This matter is considered more fully in succeeding chapters, where practical methods of making a soil fine and mellow are described.

THE WEIGHT OF SOILS

This depends upon their composition and compactness. It is of interest to the farmer chiefly as an indication of the amount of vegetable matter that a soil contains, because this influences its value for cropping. The coarser the grains, the heavier the soil; humus makes a soil lighter. A heavy soil—one weighing over 80 lbs. per cubic foot—is likely to be benefited by the addition of humus. As the term is commonly used, however, a heavy soil is one that is tenacious, and refers to texture, not to weight.

Schubler gives the average weight of a cubic foot of dry soil as follows:

Sand	100 lbs.
Garden Soil rich in humus	70 lbs.
Peat Soil	30—50 lbs.

The weight of the soil on an acre of land is so great that if a very small percentage of it is plant food this may amount to a very large quantity per acre. An acre of clay loam, nine inches deep, weighs about 3,000,000 to 3,500,000 lbs. Suppose this soil contains only one-tenth of one per cent. of nitrogen, which is an average amount of that plant food; the acre would contain, in the first nine inches only, 3,000 to 3,500 lbs. of nitrogen. Compared with this amount, the 30 to 75 lbs. of nitrogen that we apply as a fertiliser to an acre of impoverished land is a mere bagatelle.

THE MINERAL CONTENTS OF THE SOIL

The basis of most farm soils is rock that has been ground into very fine particles by frost, air, water.

etc., and mixed with the remains of plants and animals. The value of decayed vegetation, or humus, in a soil is so great, and the farm practices resting upon this fact are so important, that this matter is treated in a separate chapter (XII).

The mineral contents of a soil depend upon the kind of rock from which it has been made. These rocks are of many kinds; the nature of a soil may often be determined by seeing specimens of the rocks it contains, provided the soil is south of the region that was covered by the great soil mixers, the glaciers. There is no mineral in any soil that cannot be found in the rock from which it came; there is no mineral in any plant that is not in the soil from which it sprang.

Soil is being made from many kinds of rocks, principally quartz, feldspar, mica, apatite, zeolites, hornblende; and various combinations of these, as granite, which is made of quartz, feldspar, and mica. Quartz and feldspar form the largest proportion of most soils. The chief constituent of all soils that have been made from rocks is silica (pure sand), which is the principal ingredient of quartz. This is because silica is the hardest kind of rock material and hence it is not dissolved and lost as rapidly.

The rocks of the earth, and the soils made from them, contain from 65 to 70 so-called "elements," the simple ingredients; as iron, carbon, oxygen. These elements, however, unite with one another to make innumerable "compounds," or combinations of several elements. This might be illustrated by saying that eggs, salt and milk are the elements or ingredients of a compound—omelet. It is the great number and the intricacy of these compounds that make geology and chemistry so complex.

No one kind of rock contains all the elements, but all of the rocks from which fertile soil is made contain at least seven of them—nitrogen, potassium, phosphorus, calcium, iron, magnesium, sulphur. No plant can grow unless these seven are present in the soil; they are the "plant foods," and constitute from 80 to 90 per cent of most fertile soils. The first four of these seven are much needed by plants and so the soil is most likely to be exhausted of them by continuous cropping; while the latter three are usually so abundant that the farmer is never concerned about how he may add them to his soil. The nature and sources of these four essential plant foods, nitrogen, potash, phosphorus, and calcium, which are the necessary constituents of fertilisers, are discussed in Chapters XI to XIV.

Besides these seven elements in the soil which are absolutely necessary for the growth of plants, a number of others are frequently absorbed by the roots of plants and used by them. Of these the most common are chlorine, silicon, aluminum, and manganese. Numerous experiments have shown that plants thrive as well without these as with them, so they must be considered as accidental or unnecessary elements.

In considering the mineral contents of the soil as a supply of food for the growth of plants, we must not forget that the soil furnishes but a small part of the material out of which plants are made. We are so actively engaged in trying to keep up the fertility of our soils by checking their wastes, and by adding to them fresh supplies of the minerals that our crops have taken from them, that we are apt to think that the plant comes from the soil alone. Yet over 90 per cent. of the crops that we

26. SAND DUNES NEAR LAKE MICHIGAN—A WIND-FORMED SOIL THAT IS VALUELESS

Sometimes drifting sand covers valuable farm soils

27. THE EVERGLADES OF FLORIDA—A SOIL BUILT LARGELY BY THE DECAY OF PLANTS

Some day these glades will be drained and will become rich farming land

28. A UNIQUE "SOIL"

These pineapples are growing thriftily upon coral rocks on Elliott's Key, Florida. There are no fine particles, as in ordinary soils, but some humus and guano are mixed with the rocks

29. THE "PARTICLES" OF THE ABOVE SOIL

The roots follow the crevices. Compare with Fig. 22

remove from a soil comes from the air. The air, not the soil, is the greatest storehouse of fertility. From the air plants get, through their leaves, three other foods—oxygen, hydrogen and carbon. These are all gases, the latter being combined with oxygen in the form of carbonic acid gas. The supply of these plant foods is, so far as we know, inexhaustible. A friend once remarked, "That is mighty lucky. I have a hard enough time now, trying to supply my worn-out soil with enough potash, phosphoric acid and nitrogen to grow profitable crops; yet you say these are only side dishes of a plant's dinner. If I had to supply it with the main dishes, or fillers, as you might call these foods that it now gets from the air, I don't believe I could have raised my family of six on these forty rocky acres of New England soil."

HOW WATER IS HELD IN THE SOIL

All fertile soils contain many tons of water, which is present in the soil in several forms. First, and most conspicuous, is what is variously called free water, ground water, standing water or bottom water. This fills all the spaces between the particles up to a certain height, which varies with different soils, and even different parts of the same field. Free water is supplied by rainfall; it frequently comes to the surface as springs and is often the source of supply of wells. If a hole is dug in any soil water will stand in it up to a certain point, which may be several inches or many feet below the surface. This point is called the "water table." The height of the water table may be judged in a general way by the depth of surface wells, but this evidence is not always reliable. It may vary at different times during the year, according to the dryness of the season.

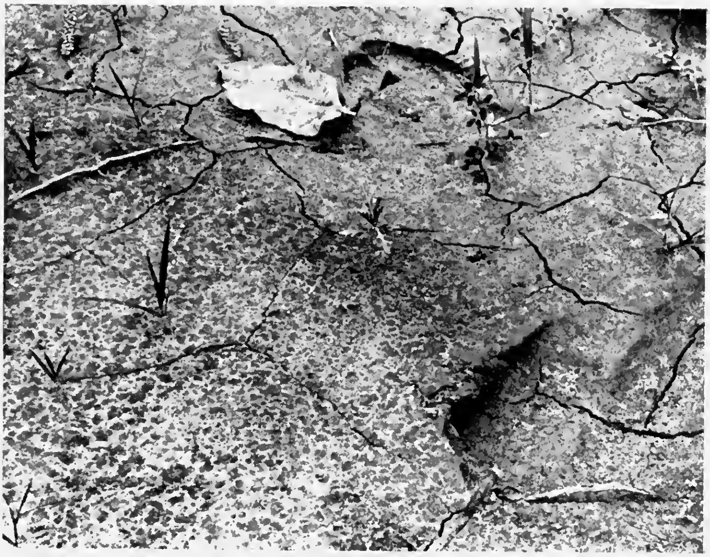
We must consider, then, that beneath all farm soils, at some depth, is standing water; that we plow and harrow above subterranean lakes, which are no less lakes because the water is not entirely free but merely fills the spaces between the particles of soil. The importance of this fact lies in its influences upon the production of a crop. If it is only two or three feet from the top of the soil to the surface of the lake, there is not enough dry soil on top for roots to grow in and the plants drown. Such soils are said to be shallow; they are of little value for ordinary farm crops until ditched or under-drained and the level of the underground lake lowered thereby. The draining of land is considered in detail in Chapter IX.

Film Water.—Water is also present in all farm soils as film moisture. Above the water table is the soil in which the roots of farm crops forage. This soil must be moist, else plants would not grow in it; but water does not fill all the spaces between the soil grains, as it does below the water table. If we look at a handful of this soil we cannot see water standing in it, but it feels moist. The water is sticking to the soil grains, covering them with a very thin film, as when small stones are dipped in water. It is held close to the grains by surface tension, or adhesion. If this soil were put in an oven and heated, the film water would be driven off as water vapour, and the soil would be left perfectly dry.

There is always a large amount of film water clinging to the grains of every soil, even in the dryest season. The dryest road dust has some film water clinging to it. The amount of water that can

30. THE THREE CHIEF INGREDIENTS OF SOILS; ON LEFT, HUMUS OR DECAYING VEGETATION; ON RIGHT, A LUMP OF CLAY; IN MIDDLE, SAND

These three are combined in nearly all farm soils in varying proportions



31. A CLAY SOIL CRACKING

The soil may be cracked for some distance below the surface. Much soil water is escaping through the cracks

32. HOW FILM WATER IS PREVENTED FROM EVAPORATING BY A SOIL MULCH

The water drawn up from the pan by this soil has been stopped by the shallow layer of loose soil on top. Thus it is in the field illustrated below

33. CORN LEAVES CURLING IN A DROUGHT

A soil mulch has been made. How to furnish crops with an adequate and equable supply of water is one of the greatest problems of the farm adhere to a single grain of soil is, of course, infinitely small, but the amount of water that can cling to all the soil grains of a field is enormous, especially when we consider the vast surface area of the grains, in the aggregate. A good farm soil often holds more than one-half its weight of film water.

Film water is far more important in farming operations than free or bottom water, for it is the direct supply of plants. No common farm crops can thrive in free water, but all must have a large area of soil that is moist with film water. Much of this supply of film water, however, is drawn from the natural reservoir of free water below.

Water absorbed from the air.—Under certain conditions the soil absorbs a small amount of water from the air. The air that fills the spaces between the particles of soil usually contains much water vapour; if the soil becomes very dry it may absorb some of this. The surface soil may also absorb water vapour from the air, especially when there are heavy fogs. This "hydroscopic" water, however, is not of much importance as a means of supplying plants with water, except in a time of great drought.

THE TEMPERATURE OF THE SOIL

The soil must be warm in order to produce crops. Most farm soils of the United States are not likely to become too warm for ordinary crops; there is far greater likelihood that they may be too cold. This is especially true in the Northern States, where the season is short, and it is very often desirable to make the soil warmer, particularly in early spring. The seeds of most cultivated plants will decay before they have had time to germinate if the temperature of the soil is below 45°; the colder the soil, the slower the seeds germinate. Only after the soil has reached a temperature of 65° to 70° do most crops grow well in it. The soil temperature that is considered most favourable for the germination of barley has been determined by experiment to be 61° to 70° F.; of clover, 77° to 100° F.; of pumpkins, 100° F.; of tomatoes, 100° F.

The growth of a crop after germination is influenced fully as much by the temperature of the soil as is the sprouting of the seeds. The farmer knows that certain crops, as onions, barley, turnips, parsnips, peas and potatoes, are "cool plants"; they can be sown early when the ground is cold, and thrive in the coolness of spring. Others, as corn, tomatoes, melons and squashes, are "hot plants"; seeds of these do not sprout well if sown very early, and the plants do not begin to grow satisfactorily until there have been summer days to warm the soil thoroughly and deeply.

The Temperature of Different Soils.—The temperature of a soil depends upon many factors, most of which are beyond the control of the farmer, but some of them he can regulate by comparatively simple means. The temperature of every soil varies widely with the season, and from day to night. The surface soil becomes warm on a hot day and cools several degrees at night, but this fluctuation rarely extends below two and one-half feet. At a depth of thirty feet the soil temperature changes little if any throughout the year, even in the Northern States. Much also depends upon the materials of which the soil is composed. The coarser it is, the warmer it gets, and the better it holds the heat; hence gravelly and sandy loams are among the earliest and warmest of soils. In Europe, gardeners sometimes put loose gravel around grape vines to keep them warm during the night. But a soil in which the particles are very small, as in clay, warms much faster than sand because the particles lie so close together that the heat passes more readily from grain to grain than in sand where the grains lie loosely. For the same reason a clay soil loses more heat by radiation than a sandy soil. Moreover, a clay soil holds more water than a sandy soil and so loses more heat because of the larger amount of evaporation. Hence, fine-grained soils, though they absorb more heat than coarse-grained soils, are colder. Sandy soils are "warm," clay soils are "cold."

Draining a Soil Warms it.—The warmth of a soil comes chiefly from the sun and incidentally from the fermentation and decay of the vegetable matter and other refuse that it contains. The temperature of a soil is modified most by the amount of water it contains. Wet soils are cold. The wetter a soil is the colder it is, at least during the summer, when warmth is needed most. It is the coolness as much as the excess of moisture and lack of air that makes corn with "wet feet" grow poorly. The chief reason for this is that it takes a large amount of heat to evaporate the excess water from a soil, and also much heat to warm the wet soil that remains, water being a poor conductor of heat, the evaporation of one pound of water from a cubic foot of clay soil makes it 10 degrees cooler. There may be a difference of 7° to 10° in the temperature of a well-drained loam and a poorly drained soil of the same character. There is one exception to the statement that the wetter a soil is the cooler it is.

In early spring we frequently have warm rains that raise the temperature of the surface soil several degrees. It is after these rains that "things just jump."

Fortunately the means of controlling this factor is largely in the hands of the farmer. The excess water may be removed, and the soil warmed by draining it. The draining of land by deep plowing, ditching, tiling and other methods is considered in Chapter IX.

Influence of Exposure on Warmth of Soil.—The "lay of the land" with reference to the compass, and the steepness of the slope, have an important influence on the warmth of the soil. The soil on a northern slope—which receives about one-third less sunshine than a southern slope, depending upon its steepness—may average 7° to 10° cooler in summer than the soil on a southern slope. The soil of a gentle southern or western slope may be 3° to 5° warmer than the same kind of soil is on a level. In the northern part of the United States the sun is always more or less in the south, so that its rays never strike level soil squarely. It is farthest in the south when the need of greater soil warmth is most likely to be felt. In early spring a slope of 12 to 15 feet in a hundred will catch the largest number of the sun's rays, being most nearly at right angles to them. Many of the rays glance off from the level land because they strike it obliquely. The practical conclusion is that a moderate slope to the south or southwest is the best site for a crop when earliness is desired; which is what husbandmen, especially fruit growers and gardeners, have known and practised for centuries.

Dark-coloured Soils Absorb More Heat.—The colour of a soil is often some index to its agricultural value and has an important influence on its temperature. A dark-coloured soil is usually warmer and earlier than a light-coloured soil. All dark substances absorb more of the sun's rays than light substances. That is why we wear light-coloured clothes in summer, and partly why snow melts faster on the dark-coloured, plowed ground than on the meadow. In Switzerland farmers sometimes hasten the disappearance of the snow by strewing it with black, powdered slate. Gardeners sometimes sprinkle a light-coloured soil with peat, charcoal and bog mould; these are called "sun traps." Melons are ripened in Saxony with the aid of a layer of coal dust. But although colour has an important influence on the power of a soil to absorb heat, it has not ability to retain heat. Schubler states that, other things being equal, a dark-coloured soil is about 8° warmer near the surface than a light-coloured soil.

This difference in the temperature of soils, due to colour, may have a marked influence upon the growth of a crop, especially on its germination. When earliness is a prime consideration, as it is with most market-garden crops, the colour of a soil may become very important. Dark, sandy loams, rich in humus, are preferred by market gardeners. Light-coloured soils may be made dark by filling them with humus. Two or three green-manuring crops plowed under will darken a light-coloured soil quite noticeably. I have a neighbour who, in three years, has transformed a poor, yellow soil into a black, retentive and productive loam by plowing under four inches of composted manure every fall. Another neighbour, under similar circumstances, has accomplished nearly as good results by plowing under muck drawn from a near-by swamp. The chief reason for adding humus to a soil is to improve its texture, but another benefit, and one that is often quite important, is to improve its colour.

The buff yellow and yellowish-brown colours of soils are usually due to the presence of iron oxides. These soils are most common south of the glaciated part of the United States, particularly in the southern Appalachian states.

The Influence of Tillage on Soil Temperature.—The way in which a soil is handled has much to do with its warmth. Uneven, ridged soil, like that left by fall plowing, loses more heat than smooth, level soil. However, ridging may warm the soil by drying it, and this usually more than counterbalances the loss of heat because of the greater surface exposed. Rolling land in fair and warm weather makes it warmer, but rolling it in cloudy and cold weather, especially if it is wet, makes it colder. Deep plowing makes the soil cooler, because loose soil is a poor conductor of heat. The decay and fermentation of farm manure plowed into a soil may raise its temperature several degrees; it produces as much heat in the soil as it would if burned in the open air. Manured soil is usually about 2° warmer in spring than unmanured soil. Thorough tillage, especially in the preparation of a seed bed, has a marked influence on soil temperature; it prevents the evaporation of soil moisture and hence keeps in the soil the large amount of heat that it takes to evaporate water. Good tillage saves heat, then, as well as water, especially in early spring. This means that the soil for early crops should be plowed early and tilled often.

THE VENTILATION OF THE SOIL

The spaces between the soil grains are filled either with water, or air, or both. This soil air is somewhat different from the free air above the surface, containing less oxygen, more carbonic acid gas and more ammonia gas. Part of its oxygen is used by the plant roots; the other gases are absorbed from the vegetable matter decaying in the soil.

Practically all of our farm crops need a well ventilated soil. The roots of plants, except certain bog, marsh and water plants, must have air to breathe. If it is denied them, because the interspaces of the soil are filled with water, the plants will die. Corn is "drowned out" in low, wet places, chiefly because the roots cannot breathe. Furthermore, air is needed in the soil to make more plant food. The air penetrates deeply into the soil and its oxygen, carbonic acid and ammonia dissolve the minerals and make the soil more fertile. The nitrogen of this air may be used as a food by certain plants (See Chapter XII), The oxygen of the soil air combines with the nitric acid produced by the decay of plants, making it a nitrate, which is a plant food. Manure which is piled loosely, so that air penetrates it readily, heats quicker and stronger than tightly packed manure; likewise a soil that is well drained and open, so that air passes into it freely, has more life, fermentation and fertility in it than a close-grained, air-tight soil. Air may penetrate the soil to a depth of many feet, depending upon its openness. Soil air changes in temperature like surface air, and continually passes up and down in currents.

Methods of Improving the Ventilation of Soil.—Any kind of tillage which stirs and loosens the soil, like plowing and harrowing, promotes a better aëration, or ventilation, of the soil. Plowing under farm manure, green manure or stubble also has the same desirable effect, since the humus thus produced separates the particles of soil and renders it more porous, hence more open to the downward passage of air. Under-draining, however, is the chief means of ventilating a heavy soil. Remove the water and the air will rush in. When the water table is lowered two or three feet, as it may be by under-draining, the roots of plants grow deeper; when they decay, they leave little channels in the soil and through these air penetrates. Earthworms and ants still further deepen and aërate the soil by following these channels.

When land is tile-drained, the tiles themselves provide a system of underground ventilation of far reaching influence. The soil of a tile-drained field is ventilated much more thoroughly than the soil of another field of the same character in which the water table stands naturally at the same height. The air in tile drains is largely surface air.

The roots of most farm crops deepen and aërate the soil, but the roots of leguminous plants, especially of clover and alfalfa, are particularly useful in soil ventilation. This is partly because clover roots are large and bore straight down into the subsoil for several feet, leaving much larger and more effective channels for the passage of air and water than the roots of grains; and also, in a very slight measure, because these plants absorb nitrogen from the soil air, thus making it necessary for more surface air to be forced into the soil to replace that which is lost.

Fortunately for the farmer, most soils are able to absorb various gases, notably ammonia, which is very valuable for the nitrogen which it contains. Advantage is taken of this fact when decaying animal matter is buried to remove the offensive smell, and when sandy loam is used behind cows in the stable. The soil acts much like a charcoal filter which is used to remove objectionable odors from water.

THE ELECTRICITY OF THE SOIL

Weak currents of electricity continually pass through the soil and through the plants it nourishes. In recent years the effect of soil electricity on plant growth has been studied quite thoroughly. The practical value of passing moderate currents of electricity over and through the soil by means of wires has been demonstrated in several European and American fields. For this specific purpose Messrs. R. & B. Bomford, near Evesham, England, have 19 acres of land with wires suspended 16 feet above the ground so as not to interfere with steam plowing. The current discharged from the wires is generated by a dynamo. This treatment is said to increase the yields of barley and wheat 25 per cent. and give a still larger increase of straw. It makes the plants germinate quicker and grow lustier. The current is turned on morning and evening until harvest. In our own country, several small fields and greenhouse soils have been treated with electricity from wires sunk in the soil, with decidedly beneficial results. The U. S. Department of Agriculture is making a special study of this matter.

Most of the beneficial effect of electricity is probably due to the fact that it makes some of the plant foods more soluble; perhaps, also, it enables the plants to take some nitrogen from the air. Only weak currents can be used; a strong current kills the plants. It is quite doubtful whether the benefit derived from the use of a weak current will make it profitable to use electricity in general crop production, for the expense of wiring a field is large; but it may be useful in greenhouses.

GERM LIFE IN THE SOIL

No soil has exactly the same composition from year to year, or even from month to month. It is constantly receiving additions of new soil from the weathering of rocks, from the decay of plants, the deposits of winds and other sources. It is constantly losing by leaching, by erosion and by the demands of plant growth. It also has numerous activities within itself that exert a most potent influence on its fertility. Some of these activities are physical, some are chemical and some are due to germ life. A few are already known and understood, but only the merest beginning has been made in the study of soil life.

Nitrogen-Fixing Germs.—One of the most interesting phases of soil life is the process called "nitrification," due to the activity of very minute germs or bacteria, and sometimes called the "nitric acid ferment." This is somewhat like the ferment that sours milk, and the bacteria in yeast that raise bread by their growth. Although the air contains vast amounts of nitrogen, this is not used by any plants, so far as is known, except to some extent by the "legumes," of which clovers, alfalfa and vetch are examples. (See Chapter XII.) Most farm crops get their nitrogen, which they need in considerable quantities, solely from the soil. This nitrogen enters into their structure, and is returned to the soil when the plants decay, but not in the same form. It enters the plant as a salt of nitrogen—a nitrate; it returns to the soil in combination with many other substances, and is called by the chemist "organic nitrogen." The important point about this is that plants cannot use organic nitrogen, because it will not dissolve in water, and all the food that plants get from the soil must be taken in liquid form. It must first be separated from its partners in the compound, and then changed into a nitrate before the soil water can dissolve it, and the roots of plants absorb it.

The work of transforming valueless organic nitrogen into valuable nitrates, which are plant food, is performed by our tiny helpers, the "nitrogen-fixing germs." They are found in all fertile soil in inconceivable numbers, busily engaged in making plant food out of all vegetation that is returned to the soil, provided the conditions are right. One essential condition is that they have plenty of food. All these ferments may be considered very minute plants; they must have food like other plants. One food of the nitrogen fixing germs is phosphoric acid, which is also one of the most important foods of ordinary farm crops. If a soil has very little phosphoric acid in it, the transformation of humus into plant food is apt to take place very slowly. The principal food of the germs, however, is humus itself. This they can use only after the leaves, stems, or other vegetation has been thoroughly incorporated with the soil and is rotted.

These minute plants need moisture and a medium temperature in order to thrive and do their work, as the yeast ferment needs moisture and a certain temperature in order to multiply and as a corn plant needs water and hot weather in order to bring forth its increase. The growth of these microscopic soil plants is checked in very dry weather as much as the growth of the larger plants above ground. Furthermore, they do not thrive in a very wet soil. The temperatures most favourable for their growth have been found to be 54° to 99° F. In the Southern States they grow the year around. Another essential condition is a plenteous supply of oxygen, such as would be had if the soil were well drained and hence well ventilated.

It will be seen, therefore, that the conditions that favour the growth of these useful workers are those that are most necessary for the growth of farm crops—a moist, well-drained soil and thorough tillage. Given these conditions, a multitude of the germs attack the rotten leaves, stems or stubble lying in the soil, or the clover, rye or cowpeas that have been plowed under, and soon change the useless organic nitrogen into a nitrate. In order to do this, however, the soil must contain a sufficient quantity of some "base," as lime, to combine with the nitrogen and so make it a nitrate. If the soil is at all acid, or sour, (see Chapter XIV), the germs cannot complete their work.

Germs That Waste Nitrogen.—It is interesting to know that there are also at work in some soils bacteria that accomplish a result exactly opposite to that of the nitrogen-fixing germs. The process is sometimes spoken of as "de-nitrification," and the germs may be called "nitrogen-wasting" germs. They feed upon the nitrates, and set free the nitrogen gas, which may then escape into the air and so be lost to the soil. These germs are abundant in wet soils; under-draining benefits the soil in more ways than by merely removing water. Thus these two, the nitrogen-saving and the nitrogen-wasting bacteria, are pitted against each other; the one is a blessing to the soil, the other may be a detriment. It is wise farming to encourage the growth of the former by providing the conditions most favourable for them—thorough tillage and excellent drainage.

Other Soil Bacteria.—These two kinds of bacteria are but a very small part of the germ life of the soil. Adametz has calculated that there are 50,000 germs of various kinds in a single gram of fertile soil. Many are beneficial, most of them are harmless, some are injurious. When the roots and stubble of a certain crop decay in the soil, a certain kind of "ferment," which is bacterial growth, is produced. If the crop is grown for several years on the same soil, after a while the soil may become crowded with the particular kind of ferment that the decay of the crop produces. The result may be that eventually the soil will no longer produce satisfactory crops of this plant, but it will produce larger crops of some other. This is the explanation, in many cases, of "clover-sick" and "flax-sick" soils and other soils that fail to respond as they used to. The practice of inoculating soils with certain beneficial bacteria is discussed in Chapter XII, with particular reference to leguminous crops.

The limits of the practical value of soil bacteriology can only be surmised at this time; but it seems not improbable that the farmers of some future generation may be able to inoculate their soils with different beneficial bacteria and secure specific and valuable results, much as the butter maker of to-day secures certain flavours with certain cultures. The field of study opened before us by recent investigations in soil bacteriology is extremely interesting and it may yield extremely important results.

CHEMICAL CHANGES IN THE SOIL

The chemical changes that are constantly taking place in every farm soil are no less numerous and no less important than the changes resulting from the work of bacteria. The elements of which the soil is composed are always shifting and changing. The compounds, which are merely combinations of several elements, are continually dissolving partnership and the elements join themselves together in new bonds, according to affinity. The nitrogen released from a nitrate by the nitrogen-wasting germs may be instantly seized by some near-by hydrogen to make ammonia. The ammonia may then be attacked by the nitrogen-saving germs and made into nitrous acid; which, in turn, may soon become a nitrate, or it may escape into the air and be lost to the soil, until brought down by rain. The phosphoric acid that the farmer applies in superphosphate or bone meal is at once seized by hungry elements and enters into several partnerships. Some of it is readily soluble in water and might leach away were there not some lime or sodium handy to catch it. That part of it which is not used by plants the first year or two may get locked up so strongly in partnerships with other elements that it becomes valueless to plants. When a potash fertiliser, as ashes, is applied to the soil, the plant food it contains would mostly dissolve in the soil water and wash away were it not that it unites with some of the "bases" of the soil and becomes "fixed." In fact, the plant food in most fertilisers applied to soils would be quickly leached or washed away, if these chemical changes did not occur and hold it until the roots of plants can use it. Plants feed, not upon the materials that we apply to the soil—ashes, bones, phosphates, guano, and the like—but upon the chemical compounds formed in the soil by them.

These and other chemical changes that all fertilisers pass through before they are absorbed by the roots of the plants illustrate what takes place with each and every constituent of the soil, whether it is essential to the growth of the plant or not. The soil is a great chemical laboratory. Numberless reactions, or new adjustments of the partnerships between the elements, occur every hour. No chemist holds the beaker or fires the great retort; the changes take place in obedience to natural laws, quietly and methodically, yet with results so far reaching that we can hardly grasp their significance. It is the business of the chemist and the bacteriologist to explore this laboratory and report how its chemical changes are effected by the different methods of handling the soil. It is the business of the farmer to keep the soil laboratory in excellent working order, by a wise and varied husbandry; and especially by giving careful attention to those principles of good farming that we already know make it run smoothly—thorough tillage, excellent drainage, and a rotation of crops.

CHAPTER III

KINDS OF SOILS AND HOW TO MANAGE THEM

SOILS may be classified according to their origin or according to their composition. With respect to origin all soils are either transported or sedentary; that is, they are composed of materials that have been moved by some natural agency, as wind, water, or ice, as discussed in Chapter I, or they have been made by the weathering of rocks or the decay of plants in the places where they now are. In one sense all soils are both sedentary and transported, since they have all received more or less material from other sources; but these terms are meant to apply in a broad sense.

SEDENTARY SOILS

In a general way the soils in that part of Northern United States which was covered by the great glacier are mostly transported, while the soils farther south, and east of the Mississippi River, are mostly sedentary. Sedentary soils are usually not deep, because the mother rock beneath weathers very slowly, being largely protected by the soil above it. The red clay soils of Tennessee, Georgia and other parts of the South, and the famous "blue grass soil" of Kentucky, derived from limestone, are excellent illustrations of a sedentary soil. They are usually very fertile.

Other examples of a sedentary soil are muck and peat, which are made almost entirely by the decay of plants, together with the little mineral material that is blown in. The plant that accomplishes the most in this direction is sphagnum moss. It is a semi-aquatic plant and grows with great luxuriance, making a thick carpet over the water. Eventually the whole surface of a shallow pond may be covered with sphagnum. Other plants get a foothold upon this—rushes, sedges, cat-tails, cranberries, and the like. "Floating" cranberry bogs are quite common on the fresh-water marshes of Cape Cod. Finally the covering of plants is solid enough and has decayed sufficiently for small water-loving shrubs, as huckleberries and alders, to get established. The floating carpet gets thicker and heavier from the decay of plants; finally it either breaks and sinks at once to the bottom of the stream or lake, or sinks into it gradually and is covered with water. Then begins the formation of peat. This process of pond, swamp, and stream filling is going on in all parts of the United States, mostly on a small scale but sometimes on large areas. One million acres of soil in the Kissimmee Valley of Florida have been made in this way. The Great Dismal Swamp of Virginia is another illustration. When drained these swamps may be very fertile.

TRANSPORTED SOILS

Transported soils are more numerous. Among the most important of these are the alluvial or water-made soils. These are rarely stony, are usually level, fine-grained and often very deep. Water usually leaves the soil it carries in more or less distinct layers; this "stratification" can often be seen in alluvial soils. The largest area of alluvial soil in the country is the flood plain or delta of the lower Mississippi. It reaches from the mouth of the Ohio southward for 1,100 miles. The whole area is flooded periodically and receives each time a deposit of the mud that gives the Missouri its Indian name, meaning "Big Muddy." It is exactly such conditions as this that have enabled the valley of the Nile to produce bountiful crops for 4,000 years without artificial fertilisation. The same process is responsible for thousands of meadows, swales, and swamps in northern United States, and it may be seen in action on the banks and at the mouth of every stream. Alluvial soils are made mostly of very fine sand, and silt and clay. They vary greatly in chemical composition, but are usually very rich.

Drift Soils.—Of even greater agricultural importance are "drift" soils, those that were formed by the action of the great ice sheet of the geologic past. They are distinguished from all others by having many rounded rocks or boulders, which were worn smooth and rounded by glacial action. Some drift soils are assorted or in layers, having been laid down by successive streams of water issuing from the ice; others are not in layers, having been deposited directly by the ice. The deposits of drift soil are not always spread evenly over the land. Sometimes the underlying rock comes to the surface, making patches of sedentary soil; sometimes drift soil is heaped into broad rounded knolls, from several feet to 300 feet high. These "morains" or "drumlins" are a distinctive feature in the farm landscape from eastern Massachusetts to North Dakota and north into British Columbia. The average depth of drift soils is about 30 to 50 feet, but in some places it is 300 to 500 feet deep, and often it is merely a skim coat of seven or eight inches over the surface.

As would be expected, the distribution of drift soils is very erratic. An acre may contain several wholly distinct kinds. There is a field of one acre near Lansing, Mich., in which about one-half of the soil is a stiff clay, one-fourth is gravelly loam and the balance, which was formerly a swamp, is muck. Who would try to advise the owner how to treat this field as regards tillage, fertilising, and draining?

All the variations in soils that affect the production of crops are not apparent on the surface; the character of the subsoil has a very important influence on the fertility of the surface soil. The subsoils of drift or glacial soils are extremely varied. The diversity of many of the soils of northeastern United States may be judged from a report of James Geikie on the different kinds of soils that he found in a cut 355 feet deep, working from the surface downward:

Sandy clay	5 feet	
Brown clay and stones	17 "	
Mud	15 "	
Sandy mud	31 "	
Sand and gravel	28 "	
Sandy clay and gravel	17 "	
Sand	5 "	
Mud	6 "	
Gravel	30 "	
Brown sandy clay and stones	30 "	
Hard red gravel	4 "	6 inches
Light mud and sand	1 "	8 "
Light clay and stones	6 "	6 "
Light clay and thin block	26 "	
Fine sandy mud	36 "	
Brown clay, gravel, and stones	14 "	4 "
Dark clay and stones	68 "	
	355 feet	

This is probably more varied than most drift soils, but it shows the extent to which the ice, and streams of water produced by the melting of ice, have assorted and mixed the soils and soil materials of the Northeast.

The value of drift soils for cropping is very variable, depending upon the material of which they are composed, and the way in which they are laid down. As a rule, however, they are fertile because they are composed of materials that have been brought together from several sources, and there is therefore greater likelihood that the essential plant foods will be present in abundance. They are apt to contain more sand or gravel and less clay than sedentary soils; hence they are usually of good texture and easily worked. But a drift clay or muck is not more valuable or manageable than a sedentary clay or muck. Those containing a fair percentage of clay are more valuable than those that consist chiefly of gravel.

Wind-built Soils.—Still another type of transported soils—those built mostly by wind—is sometimes very valuable for cropping. The wind-formed soils of Washington and Oregon are composed of fine basaltic ash. The loess and adobe soils discussed further on have been made partly by wind. More frequently, however, wind-formed soils are of little or no value, being composed mostly of fine sand; and moreover, they may cover and ruin other soils that are valuable. On the southeast shores of Lake Michigan sand dunes 100 to 200 feet high have buried large areas of forest. The sand hills of Wyoming cover about 20,000 square miles of territory on both sides of the Niobrara River. These are a part of the "Bad Lands," a dreary waste of naked, rounded hills, composed chiefly of yellowish or grayish sand, or sandy clays blown by the wind, and extending over portions of Nebraska, Colorado, Wyoming, and Utah. The "Pine Barrens" of Michigan and of the Atlantic Coast are other illustrations of drift soils worthless for agricultural purposes.

COMPOSITION OF SOILS

With respect to composition, all soils are made of four ingredients—sand, silt, clay and humus. No one of these ingredients alone makes a valuable soil, nor is it possible to find any soil composed entirely of a single grade. The most valuable soils—the loams—are a mixture of the four ingredients.

The basis upon which the four ingredients of soils are separated is the size of the grains, and here an arbitrary division is made. This is called a "mechanical" analysis" of the soil as distinguished from a chemical analysis, described in Chapter XI. The coarser materials are screened from the soil by passing it through several sieves, with meshes of different sizes. Fine sand, silt, and clay are separated by allowing them to settle in water, the fine sand settling first, then the silt and finally the clay. The approximate size of the different ingredients is:

Coarse sand	$\frac{1}{25}$	to $\frac{1}{50}$	of an inch in diameter
Medium sand	$\frac{1}{50}$	to $\frac{1}{100}$	" " " " "
Fine sand	$\frac{1}{100}$	to $\frac{1}{250}$	" " " " "
Very finc sand	$\frac{1}{250}$	to $\frac{1}{500}$	" " " " "
Silt	$\frac{1}{500}$	to $\frac{1}{2000}$	" " " " "
Fine silt	$\frac{1}{2000}$	to $\frac{1}{5000}$	" " " " "
Clay	$\frac{1}{5000}$	to $\frac{1}{250,000}$	" " " " "

Sand is made chiefly of particles of quartz, and all its grains are large enough to be readily separated and distinguished without a microscope. The grains of sand are large because quartz is very hard, almost as hard as diamond; hence the grains weather very slowly. Sand contains very little plant food, since the spaces between the large grains allow water to pass through very readily. The chief value of sand in a soil is in making it mellow, porous and warm. Mix a handful of sand with a handful of stiff clay and note that the latter is made much more workable, but less retentive of moisture.

Clay is made entirely of very fine particles, so small that a single grain cannot be seen without a microscope. It would take 5,000 large grains of clay laid side by side to measure an inch. Clay may be made from any kind of rock, as silica, limestone, mica and feldspar. Clay is exactly opposite to sand in its physical properties. Being very small, clay grains sink but slowly in water, so they are often carried long distances by streams and lodge only when the current becomes sluggish. The sediment that settles to the bottom of a glass of muddy water is mostly clay. Because it contains so many very small spaces between the minute grains, clay absorbs water slowly, but holds it tenaciously. Hence it is adhesive and unmanageable when wet. Pure clay is a powerful cement. Clay in a soil gives it body and richness and increases its ability to hold water, but if a soil has too much clay it is wet, cold and hard to handle.

Silt is a name given to the grains of a soil that are intermediate in size and in character between sand and clay. It holds water well and is especially rich in plant food. For these reasons a soil that contains a large proportion of silt is apt to be mellow and productive. Most of the soils of the western prairies, and in fact a large part of the grain soils of the United States, are composed mainly of silt. A high proportion of silt in a soil has about the same effect upon it as a large amount of clay, making it tenacious of water and of plant food. Many soils said to be clayey have more fine silt in them than clay.

Humus is mostly decayed vegetation. All the vegetable matter in a soil, however, is not humus; the carpet of rotting leaves beneath a forest tree is not humus. Not until this is entirely decayed and has become a loose, black mould, in which neither leaf nor stem may be discerned, is it humus. There are all stages between this and the vegetation that is just beginning to decay, and all have value. The value of humus in a soil for increasing its capacity to hold water, for making it mellow, and for furnishing plant food has been stated in preceding Chapters, and is considered yet more fully in Chapter XII.

THE LEADING TYPES OF FARM SOILS

From these four materials—sand, clay, silt and humus—many kinds of soil have been made, differing widely in the proportion of each ingredient, and in agricultural value. The relative amounts of each material in a soil influence its texture, the way it responds to heat and moisture, and its value for cropping fully as much as its richness in plant food. While nearly every fertile soil contains all four, most soils are pronounced one way or another. Thus we have, as a broad classification of agricultural soils, sandy soils, clayey soils (which include soils that are mainly silt), and humus soils, in which each of the respective ingredients predominates to a greater or less degree. Then there are the loams, which are combinations of sand, clay, and humus, the sand predominating in sandy loams, and the clay in clayey loams. These are the common types of soils with which the farmer has to deal. Their characteristics, and brief suggestions on how they may be handled to best advantage, are given in the following paragraphs.

SANDY SOILS

Soils containing 80 per cent. of sand and less than 10 per cent. of clay are called sandy. These soils are usually poor in plant food and are leachy, especially if the sand grains are large. The finer the sand the more valuable is the soil, as a rule. In dry weather crops on sandy soils are quickly parched. These soils absorb little if any water from the air. On the other hand a sandy soil dries out very soon after a rain, so that it can be worked quickly. Moreover, a sandy soil is warm, because the large quartz grains hold heat well; they are miniature soapstones. If kept wet and if enriched, sandy soils respond with large crops, especially if the farmer fills them with humus. Heavy dressings of barnyard manure have a very beneficial effect upon sandy soils, not merely because manure enriches them in plant food, but more particularly because the humus in it clogs the large spaces between the sand grains, making the soil less porous. A green crop plowed under has the same effect. Manures and fertilisers should not be applied to sandy soils long before the plants need them.

Some of the most valuable early truck and fruit lands, notably in Delaware and New Jersey and elsewhere along the Atlantic seaboard, are sandy soils that have been built up and given greater body and life by green manuring. Soils known technically as "Norfolk sand," the "Fresno sand" of California, and the "Miami sand" of inland regions are other examples. They are especially valuable where earliness is essential and are adapted for quick-growing crops, particularly Irish and sweet potatoes, peas, peppers, watermelons, canteloupes; also early fruits, especially strawberries and peaches. They are too light for wheat, oats, rye and other general farm crops. The main point to look after in handling a sandy soil is to fill it with humus. It should not be plowed deeply, as this loosens the soil still more. Heavy rolling compacts the grains and is often very beneficial on soils of this type. Liming will bind the particles together, making the soil more compact.

SANDY LOAMS

When a soil contains from 60 to 70 per cent. of sand it is commonly called a sandy loam; while a soil that is 70 to 80 per cent. sand is called a light sandy loam. The gradations between the two are insensible. The balance of these soils is clay silt and humus. These are valuable soils for market garden crops, because they are early, hold a fair amount of water and fertility and are easy to work. Sandy loams are especially desirable for all the trucking crops mentioned as succeeding on sandy soils and are fairly good for general farming crops, although rather light for this purpose. Corn, cotton, rye, potatoes, and the common garden vegetables, as melons, squashes, turnips, tomatoes, beans, etc., enjoy this type of soil. Clover and alfalfa will do well upon it, provided the soil is deep; black raspberries and peaches also thrive upon sandy loams. However, they are preëminently vegetable gardening soils.

In handling these soils the important thing to do is to remedy their chief defects, which are leachiness, and, as a consequence, deficiency in available plant food. They need to be fertilised highly and are likely to be benefited most of all by stable manure, which corrects both defects. Usually it is not best to plow them in the fall and leave them over winter without a cover crop, because much plant food will be lost by leaching.

CLAY SOILS

Soils containing 60 per cent. or more of clay and silt are commonly called clay soils. A large part of so-called clay soil may be silt. Some clay soils are 80 to 90 per cent clay and silt; these are usually worthless for farming. Clay soils are exactly the reverse of sandy soils in nature and in agricultural value. The very small spaces between the exceedingly fine grains admit air and water very slowly. When a clay soil is once thoroughly wet it is sticky; when dry it cracks and bakes and becomes cloddy. Hence, such soils are not only hard to till, but they are also hard on plants, often being too wet in a wet time and too dry in a dry time. The difficulty lies in the slowness of clay soils to move water. The dark, bluish-gray colour which so many clays possess is mostly due to the presence of iron oxide or iron sulphide; the red or yellow, is due to the presence of peroxide and protoxide of iron.

On the other hand, clay soils are usually rich in plant food, especially in potash. Plants once established in them, particularly deep-rooting plants, are carried ahead vigorously. The farm crops that succeed most generally on clay soils are the cereals, grasses and some tree fruits, notably the apple, pear and plum. Clay land is especially valuable for hay.

The treatment of a clay soil should be that which will remedy its chief defect—heaviness. Underdrainage will do much to accomplish this result. Underdrainage removes the surplus water in a dry time and promotes aëration and warmth in these soils, many of which are sadly deficient in these respects. The fine particles of clay may be separated from each other and the soil loosened and lightened by mixing them with particles of humus or sand. Barnyard manure or a green manure crop will lighten a heavy clay soil, as well as give body to a light sandy soil. Manures applied to clay soils in the fall lose but little of their plant food by leaching. It is rarely practicable to haul sand upon a clay soil and plow it under, because of the expense, but if this can be done expediently the result will be gratifying. It often happens that a muck bed, marking the place where a small swamp formerly existed, is adjacent to clay land. Three or four inches of muck spread upon clay soil is of immediate and lasting benefit.

Extreme caution should be used in plowing and tilling clay soils. If plowed when too wet they become cloddy. There is a certain point between wetness and dryness when a clay soil crumbles quite readily; it should be tilled only at this time, so far as is possible. The texture of a clay soil may be ruined for several years by one injudicious plowing, when it was too wet. Unless the soil is very tenacious, and "runs together" or "puddles" if left bare over winter, clay land may be fall-plowed to advantage, leaving it rough and exposed to the mellowing action of freezing and thawing. The crust that forms so easily over the surface of clay soil in summer should be prevented by frequent shallow tillage. Something may also be done to improve the texture of clay soils, in certain cases, by liming them. This causes many of the fine grains to stick together, forming larger grains, thereby making the soil looser and more porous. The liming of soils is considered in Chapter XIV.

CLAY LOAMS

These are quite similar to clay soils, but they contain less clay and silt, and more sand. A soil carrying 30 to 40 per cent. of clay is generally classed as a clay loam, and a soil carrying 40 to 50 per cent. of clay as a heavy clay loam. A clay loam usually has 25 to 35 per cent. of sand, and a heavy clay loam 10 to 25 per cent. of sand. The fair proportion of sand mixed with the clay in this type of soils makes them easier to handle than clay soils, and more porous. They are apt to be rich, especially in potash, not only because of the store of native plant food, but also because they are very retentive soils. The plant food in fertilisers that may be applied to them is not quickly leached away, as it is on sandy soils, but is held very tenaciously by this more compact soil. Crops upon clay loams are not likely to suffer from drought as badly as on clay soils, because water moves through them more freely. Some clay loams, however, are cold and wet. These soils more than any other type, are benefited by underdrainage.

The clay loams are suitable for a larger range of cropping than any other soils, except the loams themselves. They are especially valuable for grass, wheat and corn. In handling clay loams attention should be given to the details of management that are beneficial to clay soils, and especially to underdrainage, judicious plowing and the incorporation of humus.

LOAM SOILS

These are the most useful "all around" soils; they combine the lightness and earliness of the sands, with the strength and retentiveness of the clays. Loams contain from 40 to 60 per cent. of sand, and 15 to 25 per cent. of clay. They "work up" easily, do not crust or crack, are well supplied with plant food, and, what is chiefly important, water moves through them freely and still they are not leachy. Practically all farm crops grow satisfactorily on a loam. It is especially suitable for potatoes, corn, market-gardening crops, and small fruits; but grasses, cereals, clover, alfalfa, and cotton, find it congenial. It requires no special treatment, except such attention to good tillage, drainage, and the addition of humus as is a necessary part of the best farm practice everywhere.

GRAVELLY AND STONY LOAMS

These are sandy loams, clay loams, or loams with an admixture of gravel or stones; all pieces of rock from 1-25 of an inch in diameter up to two or three inches are gravel—larger pieces are stones. Gravelly and stony loams are most common in the North, especially in the Northeastern states, where they were formed by the work of glaciers. Most of the pieces of rock are worn smooth. The presence of a large quantity of small stones in a soil makes it warmer, for rock absorbs heat more freely than soil, and loses it more slowly, thus keeping the soil warmer at night. If the stones are numerous and large, however, the increased difficulty of tillage may more than offset the advantage of earliness. For this reason a gravelly loam is usually more valuable than a stony loam. A gravelly or stony sandy loam is sought when extreme earliness is desired. Some of the most profitable strawberry plantations in New York are on this type of soils. As a rule they are better adapted for fruits, especially small fruits, than for staple farm crops.

PEAT AND MUCK SOILS

Peat and muck are the black soils produced when a luxuriant growth of plants decays slowly under water for many years. When the plants are but partially decayed, so that the soil is very spongy and fibrous, it is called peat. When decay has progressed further, and especially when the soil is alternately submerged and exposed to the air, becoming finer, blacker and no longer fibrous, it is called muck. Muck is an advanced stage of peat. Both are passing through the same process by which coal has been formed.

Peat and muck swamps and bogs are found all over the eastern United States, and in many parts of the West except in the arid regions. Most of our fresh water marshes are muck or peat. They are not so numerous here, however, as in many parts of Europe, especially in Ireland, one-tenth of which is said to be peat bogs. These soils are being made to-day, where shallow lakes, ponds, streams, and swamps are being filled by the growth of plants, especially the sphagnum moss; but less peat is being made now than during a period in the earth's history when rainfall was more abundant.

The Value of Peat and Muck Soils.—The value of peat and muck soils for farming depends chiefly upon the amount of mineral matter they contain and upon their drainage. Some of these soils are nearly 100 per cent. humus, others are but 30 per cent. humus. Considerable fine rock or mineral soil may be blown upon peat or muck land; the more of this the better. Muck, being further advanced in decay than peat, is more apt to become serviceable as a farm soil than peat; it is, moreover, more compact and usually contains more mineral soil, having been above water longer.

Many muck and some peat soils need only to be drained in order to become valuable for cropping. Thousands of acres of land, especially fresh marsh land, have been reclaimed in this way. In Michigan and Ohio reclaimed swamp lands are largely used for growing celery and onions. Open ditches are most commonly used for this purpose, these soils being so loose that tile drainage is usually impracticable at first, except for the most earthy mucks. The result of drainage is to lower the water table so that air can penetrate the soil. Many peats, and some mucks in which the decay has not progressed far, do not make good farm land, even after they are drained; they become very dry and chalky, having scarcely more power to draw up the free water beneath by capillary action than a pile of chips. Not until several years after drainage, when the fibrous matter has been broken down and made into fine soil, are some peat and muck soils able to grow profitable crops.

When well drained and sufficiently fined to permit the free movement of water upward, these soils are especially suitable for cabbage, cauliflower, celery and peppermint. On the finest of mucks the grasses and a variety of vegetables are successful. In southwestern Massachusetts, and in New Jersey, Wisconsin, Michigan and some other sections, peat and muck bogs are ditched, the surface covered with 3 to 6 inches of sand, and then planted with cranberries.

In handling muck and peat soils one must remember that they are largely humus and always contain a large per cent. of nitrogen, the chief fertilising element produced by the decay of vegetation. In fact, muck often contains as much nitrogen as barn manure, although but little of this is in available form, being in the form of organic nitrogen. These soils usually need fertilising with the mineral plant foods—potash, phosphoric acid, and lime. Wood ashes are especially beneficial to muck soils. As a rule they do not respond to manuring as satisfactorily as soils that contain more mineral matter.

LOESS SOILS

The name "loess" is applied chiefly to large areas of soils that have been carried to their present resting places by water or wind, and which show no layers, being of the same nature throughout. The largest deposit of loess soils in the United States is the alluvial loess of the great Mississippi Valley, including thousands of square miles of the "prairie" soil of the central states. They are found in southern Michigan, Ohio, Illinois, Indiana, Iowa, Kansas, Oklahoma, Tennessee, Arkansas, Missouri, Kentucky, Alabama, Mississippi, Louisiana. Smaller areas of alluvial loess soils are found in the valleys of the Connecticut, Ohio, and other rivers; while wind-formed loess soils are found in California, Washington, Oregon and many other western states. There are large deposits in the valley of the Rhine, the famous steppes of Russia and the inland plains of China. Loess soils are noted for their great depth and remarkable fertility. In China they have produced bountiful crops for over three thousand years, with little apparent diminution of fertility. The richness of our own loess lands in the central West is well known. There the soil is from 5 to 150 feet deep. Although loess soils may differ very widely chemically, they are all about the same physically—a fine silt or clay, possessing great tenacity. Most of the loess soil of the West contains from 55 to 75 per cent. of silt and from 6 to 15 per cent. of clay.

ADOBE SOILS

These peculiar soils are found only in the arid West, especially in Utah, Arizona, southern California, New Mexico, western Texas, and in the elevated valleys of Colorado and New Mexico. They consist very largely of clay and silt, partly worn down from surrounding high land

and partly blown there from elsewhere. They are exceedingly sticky when wet and bake very hard when dry, so that they are used for building purposes. This makes them very hard to work; in short, they are aggravated clay soils. When they are wet enough they are remarkably productive, as they are unusually rich in plant food. Some adobe soils are very deep—those in some of the valleys of the arid regions being over 2,000 feet deep.

Adobe soils are usually light buff or gray, except when they contain a considerable quantity of humus, which makes them darker. They are very fine grained; no grit is felt when adobe is rubbed between the fingers. The depth, fineness and virginal fertility of adobe soils, since they have lost very little from leaching, makes them wonderfully productive. These soils are quite similar to the loess soils of the Central West.

SALT MARSH SOILS

All along the Atlantic Coast, and especially in New England, are thousands of acres of marsh land that some day will be used for farm crops. They are made largely from soil that has been worn by the sea from the rocks on the coast. Each wave that curls its crest over the "stern and rock-bound coast" wears it away to some extent, as is witnessed by the honeycombed rocks at Marblehead and elsewhere. The headlands that project into the sea are worn down and strewn upon the beach as sand. Each wave that comes tumbling in grinds these rock particles a little finer—we can hear them rustle and grind against each other in the undertow. After a while the coarse sand of the beach becomes fine sand or mud; it may then be carried out to sea by the undertow or deposited along the inlets and bays by coastwise currents. The latter case marks the beginning of a salt marsh soil. As soon as it gets fairly well started, though still covered with water, the soil is occupied with a dense growth of eel-grass. This accumulates more soil; sea weed, dead fish and other refuse collect and the soil thickens rapidly. Finally it is raised above the tides and the eel-grass gives place to other grasses which slowly extend to the beach over the mud flats. In the course of time farmers cut from these flats "salt hay," which is much relished by cattle.

All salt marshes are likely to be overflowed occasionally. It is necessary to drain them thoroughly and to prevent the overflow of salt water by diking before they can be used for ordinary farm crops, which object to so much salt in the soil. It is stated that there are over 200,000 acres of very rich salt marsh land between New York City and Portland, Me., which would be worth $20,000,000 if reclaimed; and that there are 3,000,000 acres on the entire Atlantic Coast that could be reclaimed. The cost of diking and draining these lands should not be over $50 per acre. A considerable area of salt marsh soils has already been reclaimed.

Salt marsh soils are particularly valuable for growing grass, onions, cabbage, celery; where they contain a large amount of muck cranberries are successful.

THE PROBLEM OF ALKALI SOILS

Between the Missouri River and the Rocky Mountains, in parts of California, and in a few other parts of the West, are large areas of alkali soils. They are found almost entirely in arid or semi-arid regions. These soils produce an insignificant growth of a few native plants and are wholly unfit for cropping until properly treated. They are called alkali soils because they contain large quantities of various salts, mostly common salt and carbonate of soda, which is ordinary washing soda. Otherwise they are normal. Thousands of acres of once valuable land have been made too alkaline for crops by seepage waters. The surface of alkali soils is often covered with crystals of the salts, making it look whitish. This is caused by the evaporation of water from the soil, leaving behind on the surface the salt that was dissolved in it. Over-irrigation, especially on heavy lands, often makes them alkaline and may ruin them. But all soils that are white on the surface are not alkali. Excellent limestone soils have sometimes been mistaken for alkali, because they had a coating of carbonate of lime on the surface. Quite frequently there are alkali spots in an otherwise fertile field, the spots varying from several feet to several acres in extent.

There are two common types of alkali soils, "black alkali" and "white alkali." The former contains chiefly carbonate of soda, which decomposes the humus in the soil and makes it very black; while the latter is a mixture of several salts, chiefly common salt and sulphate of soda. Black alkali is much more injurious to plants than white.

The effect of alkali upon plants depends chiefly upon the kind of plant and upon the amount of salt in the first foot or two of soil. Some plants cannot stand alkali at all, some are tolerant of it, a very few prefer it. The plants that tolerate it are mostly native salt bushes and grasses. Of cultivated plants, sugar beets, alfalfa and sweet clover are most tolerant, especially sugar beets. The grains are impatient of it, but rye and barley appear to stand it better than the other cereals. Practically all the common farm crops will not thrive in alkali soils, but after the salts are removed from these soils they are found to be remarkably fertile and produce very large crops.

How to Treat Alkali Soils.—There are two methods of improving alkali soils; the alkali may be removed, or it may be changed into another form. The most common and most efficient way of removing alkali, whenever non-alkaline water can be had in abundance, is to irrigate the land and drain it. If persisted in, irrigation and drainage usually effect a permanent cure. Irrigation washes the salt out of the soil and drainage carries it off. The waters of some streams and wells, however, contain much alkali and are not suitable for irrigation. Irrigation without drainage may make a soil more alkaline, by bringing more of the salts to the surface. Under-drainage alone is usually effective, especially for small areas that can be drained at slight expense, but it is too expensive to be practicable except for land having a high valuation.

In irrigating alkali land the entire surface of the soil should be flooded to remove the salts. In experiments by the Bureau of Soils in Utah a 40-acre tract of waste land containing 2 1-2 per cent. of salt, or 6,650 tons to a depth of 4 feet, was flooded with 57 inches of water per year. Of this amount 45 inches were recovered as drainage, and this drainage water contained 2,401 tons of salt. In other words one-third of the alkali was removed in one year. The cost of this work is from $16 to $30 per acre.

The injurious salt may be changed into another material that is less harmful by dressing the soil with gypsum, or land plaster. An application of four to six hundred pounds per acre is considered sufficient. This treatment is valuable only for black alkali. When a quarter or more of the salt is on or near the surface, as is often the case, it is sometimes practicable to scrape the surface and cast the scrapings elsewhere.

Certain plants, notably greasewood and the Australian Salt-bush, thrive on alkali soils and take large quantities of salts from them. Occasionally it is practicable to crop soils that are very alkaline with these plants for several years, to remove part of the salts. The plants should not be burned on the land, however; ashes of all kinds and especially these, make the soil more alkaline. A crop of Australian salt bushes produces 15 to 20 tons of excellent green forage per acre, or 3 to 5 tons of dry forage. This plant grows well upon black alkali.

Some soils that are very badly alkaline may not be worth the attempt to reclaim; those that are only mildly alkaline it will certainly pay to reclaim, providing they possess the other requisites of a fertile soil. Usually it takes several years to completely remove the objectionable salts, but if the soil is under-drained a fair crop can be grown upon it the second season. Deep plowing should be given to all soils that are more or less alkaline. Thorough tillage lessens the evaporation of water and hence lessens the amount of salt deposited upon the surface. Hilgard says, "When the alkali is not very abundant nor very noxious, frequent and deep tillage may afford all the relief needed. More than half the alkaline land in this state (California) that the people are afraid to touch requires no more remedy than thorough, deep tillage, maintained at all times." Liberal dressings of manure, especially horse manure, are very beneficial.

Alkali soils are apt to be deficient in nitrogen, because the nitrogen-fixing germs are not able to do their work when there is much alkali present. It is stated by Snyder that if a few loads of soil from fertile land are sprinkled on alkali spots the beneficial germs will be introduced and much good will result. After steps have been taken to remove the excess of salts the land should be cropped first with plants that are not very impatient of alkali. Oats is considered one of the best crops for this purpose.

Practically all farm soils contain some alkali, but wherever rainfall is plentiful the salts are washed away before they accumulate sufficiently to injure plants. A very little alkali in a soil is beneficial. In fact, it is necessary to apply lime to some acid soils in order to make them sufficiently alkaline to be most productive, as is noted in Chapter XIV

THE SUBSOIL

The soil immediately beneath the richest part of the surface soil is called the subsoil. It may be of any depth, and extends to the underlying rock. The distinction between the soil and the subsoil, as the two names are commonly used, lies almost entirely in the colour and texture, due to the greater amount of humus near the surface. In cultivated land there is usually a more or less distinct line between the rich, black surface soil and the poorer and lighter-coloured subsoil. In most soils, especially in the East, this line marks the depth of plowing. The depth at which the vegetation that gives the surface soil its black colour and looser texture has been buried is about nine inches. Many soils, especially those made by wind or built by water, and peat and muck soils, show very little if any difference in colour or texture between the first nine inches of soil and that below.

In nearly all cases the subsoil contains less available plant food than the soil above because it is not affected as much by weathering, being protected, and because it is less affected by acids resulting from the decay of vegetation, since it contains less humus. We might call the subsoil rotting rock, and the soil rotted subsoil. This is a providential arrangement. If the plant food in all the soil, down to bed-rock, were as easy to lose as that in the first nine inches of soil our fields would become unproductive much sooner than they do now. The subsoil is a store of plant food that is held in reserve. We should look upon the rocks, stones, pebbles and subsoil of our fields as so much potential plant food. It is being doled out to us from year to year as fast as it can be used to advantage.

As the surface soil slowly wears away and is carried off in crops, the subsoil gradually becomes surface soil. The roots of deep-feeding plants, as clover and alfalfa, bring up plant food that they secure below the roots of ordinary crops. When these crops are cut, and the stubble and roots plowed under, a part of the plant food that the subsoil has contributed to their growth is returned to the surface soil, enriching it. Earthworms bring to the surface subsoil that has never seen the light of day and this adds richness. A plowing somewhat deeper than usual may mix an inch or more of light subsoil with the surface soil. This may reduce the crop for a year or two, or until the raw plant food in the subsoil has been acted upon by air, water, and soil acids, but eventually the surface soil is enriched by the fresh material.

It is advantageous for a sandy soil to rest upon an impervious clay subsoil, and for a clay soil to be underlaid with a sand or gravel subsoil; both subsoils help to correct the defects of the soil above them. A deep gravel or sandy subsoil, however, is usually a disadvantage, as it allows plant food to leach down beyond the roots of plants.

ANALYSING THE SOIL AT HOME

The determination of the relative proportions of sand, silt, clay, and humus in a soil is called a "mechanical analysis," as compared with a "chemical analysis," in which the kinds and the amounts of the different plant foods are determined. It is not always possible to have the soil analysed by a chemist, but it is always practicable for a farmer to determine himself, roughly, the relative amounts of the four ingredients that his soil contains. A mechanical analysis should point out the deficiencies of the soil much better than simply viewing it on the surface.

A close examination of a handful of the soil will reveal much concerning its composition, especially if a miscroscope or even a pocket lens is used. Note the colour, whether dark or light; look closely for the tiny black particles of humus that are likely to be the cause of the dark colour, and are a sign of good texture and large water-holding capacity. Rub the soil gently between the thumb and forefinger to determine the size of the particles. Are they mostly coarse or fine? If the soil feels distinctly gritty it probably contains a considerable amount of sand; if it feels quite smooth and makes a very smooth, sticky paste when water is added to it, it contains a large percentage of clay or silt. Take a handful of moist—not wet—soil and squeeze it hard. If the ball of soil crumbles quickly and freely when the pressure is removed the soil contains sufficient humus or sand and is likely to prove of good texture and easy to work. If, however, the ball of moist soil retains its shape to a considerable extent, remaining hard and compact, it indicates that clay and silt predominate and that the soil will need to be handled carefully.

A more accurate test for clay, silt, sand and humus may be made in the following manner. Take a small sample of moist soil, as it is found in the field, say a quart; screen out all except fine particles, and weigh it very carefully. Spread it thinly on a pan and set it in a very moderate oven or on the back of the stove, where it will dry slowly, but not burn. When it is perfectly dry weigh it again. The difference shows the amount of water that the soil contains, all of which has been driven off as vapour of water.

Place this dry soil upon a coal-shovel above hot coals, or on a pan placed in a very hot oven. The humus in it will begin to smoke. If the soil is kept very hot for two or three hours practically all of the humus will burn, leaving only the "ash" or mineral part of the soil. A fairly reliable measure of the amount of humus that the soil contains is secured by comparing the weights before and after burning. All soils that have a fair proportion of humus and are therefore most valuable for farming, should shrink considerably in bulk and in weight by burning.

Separating the Sand, Silt and Clay.—After the humus is burned out of this soil the sand, silt and clay remain. These being pieces of rocks, or mineral matter, they will not burn like humus, which is vegetable matter. A simple way to separate the three ingredients is to put the soil into a tall, wide-mouthed bottle; one holding two quarts will answer, but a larger one is better. Fill this full of water and shake it violently until all the soil is mixed with water. Stand it on the table and watch the soil settle. If the soil contains coarse sand this will settle almost immediately, being largest and heaviest. Medium sand and fine sand will settle more slowly. Part of the silt and clay will remain suspended in the water for many hours. After several days, or when the water is clear, all the soil will be deposited in the bottom of the jar; the sands on the bottom, then silt, and clay on top. These ingredients may not be deposited in well-defined layers, because sand, silt and clay are arbitrary terms, used to designate soil grains of certain abitrary sizes, for the sake of convenience in describing them. In some cases the sand may grade into the silt and the silt into clay imperceptibly; in other cases ill-defined layers can be seen. In any case a close scrutiny of the way in which the soil settles and of its appearance after it settles will enable one to estimate roughly the proportions of sand, silt, and clay that it contains.

It will pay a farmer to test the different types of soil on his farm in this way, and especially to test several different soils at the same time and compare them. The results of these simple experiments will bear out and emphasise field observations on the agricultural value of these soils, or they may indicate a weakness where none is suspected. It is well to take a dozen or more samples of soil from different parts of a field in which the soil is all approximately similar, to mix them and to take from the combined lot the sample of soil that is tested. This makes it quite certain that the results obtained represent the field fairly.

The Bureau of Soils of the United States Department of Agriculture is making a "soil survey." The types of soils in all the important agricultural sections of the country are being studied. About 100,000 square miles of land in different states have already been studied and reports issued. These reports should be very useful to the farmers in these sections. They may be obtained of the Division of Publications, Washington, D. C.

CHAPTER IV

SOIL WATER

PROBABLY no other phase of modern farming, except the ever pressing problem of how to keep up the fertility of the soil, is now receiving more attention than the problem of how to maintain an adequate supply of soil water. The farmers of our vast arid regions, both in the irrigation and in the dry-farming sections, pay scarcely more attention to it than the farmers in the states east of the Mississippi, where the rainfall is supposed to be sufficient for ordinary crops.

It is frequently stated that the lack of sufficient water at the right time does more to reduce the yields of farm crops in the United States than the lack of available plant food. This does not refer particularly to the great droughts, which may reduce the corn crop of the whole Mississippi valley 50 per cent.; nor even to the local droughts, which sere the meadows and shrivel the gardens in scattered localities. The greatest losses from lack of water are not from noticeable droughts, but from the unnoticed dryness which merely lessens the crops year after year, reducing the average and lowering the standard. There are a few restricted sections of the country where the problem of soil water is not pressing; but in most parts of the United States a paramount problem in crop production is how to supply moisture at the right time and in adequate quantity. If a man handles his soil in such a way that it is in the best condition to receive and hold a limited rainfall, he has taken the most important step in solving the coördinate problem of how to maintain its fertility.

THE AMOUNT OF WATER NEEDED BY PLANTS

It takes a very large quantity of water to mature even an ordinary crop. Irrigation farmers appreciate this much more than farmers in humid regions, because they can see it in bulk. Hellriegel has determined the amount of water necessary for the growth of average crops of the following plants: clover, 400 tons per acre; potatoes, 400 tons; wheat, 350 tons; oats, 375 tons; corn, 300 tons; grapes, 375 tons. This does not take into account water that is constantly being evaporated from the soil in which the crop is growing; it considers only the water used by the plants themselves. At the Iowa Agricultural Experiment Station it was found that the loss of water in growing a ton of clover hay, including what was used by the plants and what evaporated from the soil, was about 1560 tons, or enough to cover an acre 13.7 inches deep. The loss of water in growing one ton of air-dried corn fodder was 570 tons, or five inches per acre; of one ton of oats, 1200 tons of water, or 11 inches per acre; of 200 bushels of potatoes, 582 tons of water, or 5.6 inches per acre. The loss of water in growing one acre of pasturage was 3223 tons, which is equivalent to a rainfall of 28 inches per acre. These interesting figures emphasise what every good farmer already knows: that an abundant supply of water is even more essential to a large crop than an abundance of plant food, and that some crops make larger demands upon the soil reservoir than others.

How Plants Drink.—It is not easy to see how it can take from 200 to 375 pounds of water to make one pound of dry plants unless one knows something of the way in which plants drink. Only a small amount of this water becomes a part of the structure of the plant. Some plants are very succulent; 94 per cent. of the strawberry fruit is sweetened water, 90 per cent. of the entire corn plant is water, and 86 per cent. of the entire potato plant is water.

Even if the crop were 99 per cent. water this would account for only a small portion of the amount that is actually lost from the soil during its growth. Most of this enormous amount of water is lost by evaporation through the leaves. Contrary to the old notion, plants do not feed by sucking up tiny particles of soil. The plant food in the soil is first dissolved in soil water, as salt dissolves in water; this is then drawn up through the roots by a peculiar process of absorption called "osmosis." The soil water drawn up by the roots contains very little plant food; it is so weak that we consider it pure water, and we drink it as it comes from tile drains or wells. Therefore the plant has to draw up a very large quantity of water in order to get sufficient food.

After the plant has used the food in this very weak fertiliser solution, the pure water is exhaled through the pores of the leaves. Put a geranium, or other potted plant, under a glass jar and note how soon the inside of the jar becomes clouded with the moisture given off by the leaves. The soil in the pot may be covered with oil-cloth or coated with hot wax to prevent evaporation from it. A plant, then, is a pump; there is a cloud of invisible water vapour rising from every grass blade and every cotton leaf. The value of some plants as pumps compares quite favourably with the pumps we buy. Eucalyptus trees are sometimes used for draining malarial swamps; willows planted at the mouth of the sink drain keep the soil from getting soggy.

RAINFALL INSUFFICIENT OR UNEVENLY DISTRIBUTED

With these figures on the actual amount of water that a soil may lose in producing certain crops, and with this explanation of where so much of it goes, the farmer may now get from the nearest Weather Bureau a statement of the average amount of water that falls upon his soil each year or he may consult the general rainfall map on another page. Then compare the two sets of figures. At first sight, it may look as though there ought to be no difficulty in watering the crop; the rainfall may be thirty inches and the crop may use but thirteen. But how much of this rainfall comes during the months when the crop is growing? How much of the rainfall previous to the planting of the crop can be saved in the soil? These two questions must be answered. The weather man will answer the first; only the farmer can answer the second, for it depends entirely upon the kind of soil he cultivates and upon the way he handles it.

A comparison between the average rainfall during the growing season, say from April 1st to September 15th, and the amount of water needed by the crop, may reveal an interesting situation. It may show, for instance, that the rainfall in those months is equal to or greater than the water used in producing the crop. This would be all right were it not for two facts; quite frequently there are years that fall much below the average in summer rainfall, perhaps considerably below the amount needed by the crop; it is the average of wet years and dry years that gives the "normal" rainfall. Then, again, not all the rain that falls becomes available for plant growth. Some of it runs off as surface water and fills the creek; some of it passes down through the soil; some of it evaporates. Very often not half of the summer rainfall can be utilised by crops.

The comparison of figures may show that the total amount of water that falls during the growing season is only about one-third as much as the crop needs. In nearly all sections of the country the situation is that not enough rain falls during the growing season to water the crops after that lost by surface drainage, evaporation and seepage is deducted. The total rainfall may be adequate, but it is unevenly distributed. The problem, then, is to store the abundant rains of winter and early spring against the dryness of summer; this is one of the most important problems in farming. The water may be stored in reservoirs and used for irrigation or it may be stored in the soil itself; the former is a Western, the latter an Eastern method. Soil storage is more common and requires more skill. The man who has learned to store water in the soil effectively has mastered one of the most important problems in crop husbandry.

CAPACITY OF DIFFERENT SOILS TO HOLD WATER

The different forms in which water is found in the soil have been mentioned in Chapter II. The water that is most valuable to the plant is that which is held by the grains as film moisture, although a large part of this may be drawn from the reservoir of free or standing water below. Soils vary widely in their ability to hold film water. In judging the value of a piece of land for cropping, it is fully as important to consider its water-holding capacity as its richness in plant food; a soil may be exceedingly rich in the essential plant foods, yet if it does not hold enough water to dissolve that food and carry it to the plants, it will produce no more than a very poor soil. Fertility consists as much in an abundance of soil water as in an abundance of plant food.

The capacity of a soil to hold water depends upon its composition and upon its texture. The lighter a soil is, or the more sand it contains, the less water it will hold. The smaller the grains, the more water the soil holds, since there is more surface for it to cling to and less likelihood that it will leach through. Each soil grain is surrounded by a film of moisture; if there are over 168,000,000,000 grains in an ounce of soil, as in some alluvial soils, the amount of surface for the water to cling to is much greater than if there are but 56,000,000,000 grains in an ounce, as in some truck soils. The more humus a soil contains the greater is its water-holding capacity, for humus is vegetable sponge. If small quantities of several kinds of soil are completely dried in an oven, and water is then added to them, it will be found that they will hold about the following amounts:

Sharp sand	25%
Clay soil (60% clay)	40%
Heavy clay (80% clay)	61%
Loam	51%
Garden mould	89%
Humus	181%

The same soils do not hold as much water as this in the field, because a large part of it drains off, as it must in order to make the soil congenial for plants. It is far more important to know how much water a soil will hold under its natural conditions in the field, after the excess water that fills the spaces has drained away and only film moisture remains. The amount of film water held by different soils is about as follows: A coarse sand holds but 12 to 15 per cent. by weight of film moisture; a sandy loam from 20 to 30 per cent.; a clay loam from 30 to 40 per cent.; a heavy clay, or a soil very rich in humus, may hold 40 to 50 per cent. of film moisture. This means that a mellow loam with a retentive subsoil holds four to five inches of water in the first foot of soil.

Although a sandy soil holds less water than a clayey soil this disadvantage is partially offset by the fact that the lighter soils give up to the plants a larger percentage of the water they do contain than the heavier and wetter soils. A light soil may hold 30 per cent. of water and a heavy soil 55 per cent., yet the lighter soil may give nearly three-fourths of its water to the crop while the plants could secure scarcely one-half of the water held by the heavy soil.

Influence of Subsoil on the Water-holding Capacity of Soils.—The amount of water held by a soil depends not only upon the character of the upper two or three feet of surface soil, in which the roots of most farm plants chiefly feed, but also upon the character of the subsoil and upon the distance to the water table. Some subsoils are retentive, others are leachy. A layer of gravel or sand three or four feet below the surface may provide perfect natural drainage, thereby increasing the amount of film water that the upper soil can hold. A hardpan of impervious clay, or of rock close to the surface, will greatly reduce the water-holding capacity of the soil, strange as it may seem. One might think that if the water could pass down only three or four feet before it strikes hardpan, the soil above would be wetter than if the water could pass down through many feet of soil. But the fact is that the shallow soils are dryest; because, in times of abundant rains, the water soon fills the soil, and then flows off as surface drainage; whereas it sinks down into the deep soil for many feet and is stored there for the future use of the crop. The first five feet of a strong loam may contain enough water to make a layer ten to twenty inches deep over the field.

Height of Water Table.—The distance below the surface at which free water is found has an important influence on the amount of film water held by the soil above it. Generally speaking the nearer the water table is to the area in which the roots of cultivated plants forage, the larger will be the amount of film water held by this soil; for a large part of this film water is drawn directly from the free water, and the nearer this is, the more abundant and equable will be the supply. The roots of most cultivated crops rarely go more than five feet deep, hence a soil in which the water table is from four to six feet below the surface is apt to be most abundantly supplied with film water. When wet land is tile drained, the level of the water table is reduced from four to six feet deep, depending upon the depth at which the drains are laid below the surface. The chief reason why wet lands are so valuable after being under-drained is that the water table is lowered only to the point where it can most easily supply the soil above with film moisture; while in lands that need no under-drainage the water table may be thirty feet deep instead of six.

HOW TO INCREASE THE WATER-HOLDING CAPACITY OF SOILS

Fortunately for the farmer he can do much to increase the amount of film water that some soils can hold, and thereby increase their productiveness. The farmer who irrigates should be interested in the subject as much as the farmer who depends upon natural rainfall to supply his crops with water; it is tedious and expensive to irrigate frequently, and he should know how to increase the capacity of his soil to hold water so that fewer irrigations will be needed.

Under-drainage is the most efficient means of improving a soil in which the water table is always so close to the surface that the soil is too wet for farm crops; or which is very wet in winter and very dry in summer. Deep plowing, harrowing, cultivating and other tillage operations also do much to deepen the soil and enlarge the reservoir, because the more a soil is pulverised the more water it will hold. The addition of humus to a soil in the form of farm manure, muck or a green manure, has a very marked influence on its ability to hold water. Furthermore, if the surface of the soil is softened, rains sink into it better. Fall plowing will leave the soil loose so that it will absorb the winter rains: if the surface is hard and compact, much of the water runs off. All of these operations are so fundamental to successful farming that each one is discussed at length in subsequent chapters.

Influence of Forests on Water Supply.—The influence of forests upon the water supply should not be overlooked. When forests near streams are removed, the soil of the adjoining farm land is made dryer, and there is increased danger of floods. The large body of humus beneath forest trees holds an immense amount of water, like a sponge—nearly twice as much as its own weight when dry. In times of drought, this water is given off gradually to adjoining dryer land. Moreover, the air near large forests contains more moisture than the air of cleared areas because the trees give off large quantities of water through their leaves: hence farm soils in deforested areas lose water more rapidly, because the air above them is dryer. There are thousands of acres of land in this country which have been cleared of timber to use for farming, but which are nearly valueless for that purpose and should revert to forest; to say nothing of the wholesale destruction of forests for timber alone. Policy, as well as sentiment, should induce every man to leave as much of his farm in woodland as is practicable.

LOSS OF WATER BY SEEPAGE

The free water of all soils is continually passing downward in obedience to the law of gravitation.

Near the surface it seeps down slowly, but as it goes deeper it gathers volume and power. If the soil is shallow, it soon strikes hardpan and overflows as surface drainage. If the soil is deep, it may sink down many hundreds of feet until it comes to some kind of a check or channel; perhaps a stratum of rock, perhaps a layer of coarse gravel. Down this it passes, joining forces with other underground currents, as the rill joins the brook and the brook joins the creek. This channel may lead it many miles away to where the stratum of rock or gravel comes to the surface. Then it gushes forth as a spring near the base of some hill, or on the bottom of some lake. Or it may not come to the surface but seek a lower level and there seep upward through the soil because of the pressure of other water behind it. Just as surface water flows down hillsides and collects in valleys, so underground water may sink through the soil of the mountain, hill, knoll or ridge, until it reaches the levels, where it may be pushed up towards the surface again by the pressure of water behind it. Many thousands of acres of farm lands are thus sub-irrigated, or watered from below, by water that has seeped down from higher land, perhaps many miles away. When drained, these soils become very productive, not only because of the equable supply of water that they receive from below, but also because this water, having perhaps travelled a long distance in seeking its level, has dissolved much plant food from the soil through which it has passed.

Loss of Plant Food in Seepage Water.—This latter phase of the seepage of soil water has a very important bearing upon the fertility of the land.

The water in the soil, both free and film, is not pure but has in it various salts and elements that it has dissolved from the soil. Some of these are plant foods. The nitrates, containing that most expensive of plant foods, nitrogen, are most likely to be carried off in this way; also the phosphates and the potash salts to some extent. Most any kind of farm plant will grow very well in the water caught from a drain tile, and nothing else, showing that this water contains as much plant food as that which the plants in the soil draw up through their roots.

The coarser a soil is, and the less humus it contains, the less able is it to retain the rain that falls upon it. It takes longer for water to seep down through clay soils, in which the spaces between the particles are very small, than through a sandy soil, in which the spaces between the grains are much larger. This is why sandy soils are leachy. The loss of water from clayey soils, through seepage, is much facilitated by the burrows of earthworms and the decay of roots, both of which open channels; also, to a considerable extent, by the numerous cracks that appear in all clay soils as they dry. These cracks are often very large on the surface; smaller though less numerous cracks are found for several feet below.

With the exception of very sandy soils, the loss of water by seepage is not likely to occur during the growing season. In most parts of the country the upper soil becomes so dry during the summer that the summer rainfall is mostly taken up or evaporated before it is lost by seepage. It is during the season when vegetation is dormant or inactive, which is usually when the precipitation is largest, that the loss of water by seepage, and the loss of the plant food dissolved in this water, is likely to be largest.

The loss of soil water by seepage can be prevented, in part, by judicious farm practice. If a leachy soil is filled with humus, either from manure or from decaying vegetation, the large spaces between the grains are clogged and water sinks through the soil less rapidly. An open, porous soil may also be compacted by rolling, which reduces the size of the spaces by crushing the grains together. Liming a sandy soil may have a slight effect in the same direction. If the soil is not left bare during the winter when a crop is not growing upon it, but is kept covered with a catch crop, as rye, the roots and herbage of this crop hold much of the water that otherwise would be lost. These operations are discussed at length in succeeding chapters.

THE MOVEMENT OF FILM WATER

In Chapter II it was stated that by far the most important kind of water in the soil is that which surrounds the soil grains like a film; because it is this, not free water, which the roots of plants use. This water is held to the surface of the soil grains by tension or adhesion, as a film of water adheres to a pebble dipped into the brook. There is also more or less water in the spaces between the grains. These films of water are not all of the same thickness. Some grains have more water on them than others; therefore parts of the soil are dryer than others. The dryness of some parts of the soil may be due to the fact that they have received less water from rainfall. It may also be caused by the roots of thirsty plants.

The movement of film water takes place in this way: The minute root hairs are always absorbing water, together with the plant food that is dissolved in it; not free water, but the film water clinging to the grains of soil. The soil grains which thus pay tribute to the plants become dry. But they touch grains that are not in direct contact with the plant pump; part of the film moisture clinging to these is passed along to the dry grains, so that both become equally moist. Now the grains a little further off have more moisture than these which have given a part of theirs to the dry grains in the grasp of the root hairs. These, likewise, give of their abundance to the soil grains less favoured. So it comes about that there is always a steady current of film water passing to every root hair of every thirsty, growing plant; not flowing through the soil, but creeping from particle to particle, and space to space.

In exactly the same way there is always a current of film water passing upward on every summer day to replace the water that the uppermost soil grains have lost by evaporation. The amount of water lost from common farm soils by evaporation may be as much as five inches a month during the summer. There must be inequalities in the dryness of the soil that are due to other causes, as difference in texture or composition; but for the most part we may think of this great volume of film water, equal to a layer of water over fifteen inches deep in the first five feet of some soils, as settling strongly in two currents —toward the surface, to replace the loss of water by evaporation, and toward the roots of plants. These invisible currents are not affected by the law of gravitation; they travel up, down, or sidewise in the endeavour to make the soil equally moist throughout its bulk. But this result is never brought to pass; it is prevented by the frequent downward passage of water, constant evaporation from the surface and continued absorption by roots.

We are not concerned about checking the current of film moisture toward the roots, except to increase it. Usually the larger the loss of film water in this way, the greater the gain to the farmer. But we are greatly concerned about the current of film water that is passing upward to the surface of the soil and is then lost in the air as water vapour. We cannot afford to lose this water; and we cannot afford to lose, even temporarily, the plant food that is dissolved in it. When the water evaporates, this is left upon the surface of the soil where it is useless to plants, until washed down into the root-feeding area. We would rather have the water evaporate, not from the soil, but through the leaves of crops, after it has given to the plants the food that it contains.

The sun is the mightiest of pumps. The amount of water that is evaporated from the soil in one summer day is astonishing even to those who have observed how quickly the soil becomes dry in midsummer after a heavy rain. King found that each square foot of an ordinary farm soil lost 1.3 pounds of water daily by evaporation from the surface.

Capillary Action.—The movement of film water in the soil is frequently called "capillary action." The soil being made of millions of tiny grains, there are likewise millions of tiny spaces between the grains, as in a pile of wheat; so it follows that there is a more or less continuous passage from one space to another, making many small and very crooked tubes—hence the term "capillary," hair-like. Film water passes up, down and sidewise through these tubes, but mostly upward, for there is where the soil is most likely to become dry. For the purpose of illustration, then, we may conceive that every farm soil is permeated with very fine hair-like tubes which reach deep into the subsoil; that it is, we will say, something like a bundle of wheat straw. The lower ends of the tubes rest upon the water table—which may be two, six or thirty feet below the surface, according to the depth at which free water is found. The upper ends of the tubes open upon the surface. Water is drawn up through these tubes, from the water table to the surface, by a kind of suction called "capillary action." Capillary action is something like the process by which oil is drawn up through a wick; the flame that burns the oil is like the sun that evaporates the water; as oil creeps up through the strands of the wick, so soil water creeps up through tiny pores of the soil. Whenever the sun is hot, or a drying wind hugs the ground, water is drawn up through these tubes. In reality the tubes are as crooked and irregular as the holes in a piece of cheese, yet the principle and the results are the same.

How to Prevent the Loss of Film Water.—How can this great loss of water—sometimes amounting to over one and one-half inches of rain in a single week—be checked? Obviously there is but one way to do it—by stopping the mouths of the tubes. One need not travel far to find illustrations of how this may be done. Turn over a board or stone lying on the ground; the soil beneath is more moist than the adjacent soil; the pores of the earth have been closed, and the current of water passing upward has been stopped. That is why fishermen hunt for earthworms beneath stones, when the weather is very dry. A layer of small flat rocks scattered over the surface of the ground would prevent a large part of the film water from escaping, were it practicable. The woodpile offers another illustration, for the soil is always moist beneath the layer of chips, showing that evaporation has been checked. But a layer of straw does just as well and is easier to apply.

Any material that is spread upon the soil to stop up the mouths of the water tubes and shade the surface from the sun, thus preventing the loss of soil water, is called a mulch. The most effective and practicable mulches are coarse hay, straw, and farm manures; not only because they are easy to apply, but also because they benefit the soil in other ways, chiefly through the humus that they add. Occasionally other materials are used to mulch the soil, as leaves, straw waste, coal ashes, sea-weed. Mulching to save soil water is rarely practised in growing common farm crops. Small fruits, especially the strawberry, currant and gooseberry and also, to a slight extent, the tree fruits, are frequently mulched with these materials.

The Soil Mulch.—The most practicable mulch in general farming is made of loose, dry soil. This is obtained by stirring the surface of the soil with the implements of tillage, as the plow, harrow and cultivator. Stirring the soil makes it much looser. The pores are broken. Water can creep from one soil grain to another only when the grains are close together—when the soil is compact. Stirring the soil spreads the grains so far apart that water cannot pass from one grain to another, or but very slowly. So it comes no further than the mouths of the tubes, which are now not on the surface but eight inches, six inches or three inches below the surface, according to the depth to which the soil has been loosened. The practical application of this fact, and other benefits of tillage, are fully described in Chapter V.

THE WATER-MOVING ABILITY OF DIFFERENT SOILS

Since soils are so variable in composition and in texture they naturally vary a great deal in their "capillarity," or their ability to move film water. This point is worth considering when selecting a farm; a soil through which water moves slowly is not apt to be very productive. The coarser a soil is, the less water it can draw up. Fill one lamp chimney with coarse sand and another with clay loam, both packed hard. Set both of them in a pan of water and note the difference in the amount of water that they draw up and the time it takes them to do it. For a while water will rise rapidly through sand, but it will not be drawn very high, because the spaces or tubes are so large. In the finer soils, especially those containing some clay, water rises more slowly, but it is drawn up very much farther. Humus increases the water-drawing power of a soil.

The importance of securing a soil with high capillary power lies in the relation this has to the water supply of crops. Film water, on which plants feed, is drawn largely from the reservoir of free water below. It is important that a soil be able to draw water freely and rapidly in order to keep the roots constantly bathed in the life giving fluid. A large crop makes a tremendous drain upon the water in the upper part of the soil during a single day. If the sun is very hot, the amount of water lost by evaporation is large; even thorough tillage cannot entirely prevent the escape of water. This means that the supply of film water in the surface soil must be quickly replenished from below, else the plants will suffer.

In some soils the water table is many feet below the soil in which the roots of plants feed; in such cases there is especial need that the water be able to move rapidly through the soil. Very sandy soils not only do not hold much water, but also have little power to transport it by capillary action. Very stiff clay soils, on the other hand, while they hold a large amount of water, regain water very slowly after having become dry, so that they frequently suffer much in a drought. When a clay soil dries it shrinks, and cracks appear not merely on the surface, but also to a depth of several feet. These cracks let in air which still further dries the soil; the roots of plants may also be torn apart and exposed, All kinds of loams have excellent water-carrying power; this fact, together with their mellowness and fertility, makes them among the most valuable of farm soils.

How to Test the Water-holding Capacity of Farm Soils.—The points that have been brought out in the preceding paragraphs will be made more concrete to the reader if he will try a few simple experiments. Get a quart each of stiff clay, sand, and the black, spongy humus beneath forest trees. Put the three samples into a slow oven and dry them for two or three hours, or until they appear perfectly dry. Stand three lamp chimneys in pans and fill one with the dry humus, one with the dry sand and one with the dry clay.

Pack each very tightly. Fill three quart jars with water and pour water slowly from one of them into the top of the chimney of humus; water the chimneys of sand and clay likewise from the other two jars. Pour in only a very little water at a time so as to allow it to settle slowly and wet all the soil thoroughly. Stop pouring water when the soil is wet to the bottom, and water begins to seep from the bottom of the chimney. Note first, how quickly water passes through sand and how little water it holds—it is leachy. Observe that the humus also absorbs the water quite readily, but holds much more of it. The clay takes up the water very slowly but holds a large quantity of it. The water left in each of the three jars shows the relative water-holding capacity of the soils.

The chimneys of soil represent actual conditions in the field; the water held by the soil in the chimneys is film or capillary water, while the water that seeps out at the bottom of the chimney is free or standing water. The same results may be secured in another way by filling several flower pots with different soils and drying them in an oven. After weighing each pot of soil separately, add water to it very slowly until it seeps out at the bottom. Set the pots away to drain. When no more water seeps out, weigh them again. The difference in weight is the amount of film water that the soil can hold.

The several types of soil on the farm may now be tested in the same way. Compare the water-holding capacity of a sandy loam with a clay loam. If you have a stiff clay soil, fill one chimney with this, another with a sample of the same soil which has had some humus mixed with it, and a third chimney with another sample of the same soil which has had some sand mixed with it. A comparison of these three samples should point a profitable lesson. If you have a very sandy soil find the influence of adding humus to it in like manner. If accurate measurements are desired, weigh the dry soil and the same soil after it is thoroughly saturated. A good soil should be able to absorb at least one-half its own weight of water; humus often holds almost twice its own weight of water, and sand from 15 to 25 per cent.

Testing the Water-moving Ability of Soils.—The ability of a soil to move water by capillary action, and to draw upon the free water to supply the needs of plants, may be determined with a fair degree of accuracy in the following manner. Take chimneys of fire-dried and well-packed clay, sand and humus, as in the previous test, and stand them in a pan. Cover the bottom of the pan with half an inch of water. Note the water creep up into the chimney by capillary attraction. It rises very rapidly in the sand at first, but is carried only three or four inches high and then stops—the spaces between the grains are too large for it to be drawn higher. Humus takes the water up more slowly but eventually the soil at the top of the chimney is wet with the film water drawn up from below. The clay absorbs water even more slowly than humus, but the surface soil of the chimney of clay is wet in a few hours. Now test in a similar manner the farm soils which you have to handle. See what effect mixing a little sand or humus with the clay has upon its water-drawing power, and what influence mixing a little humus with the sand has upon its capillary power. Compare the capillary power of sand when it is put into the chimney loosely, and when it is packed into the chimney very firmly; it may suggest the value of rolling.

The chimney of soil is a field in miniature; all fertile soils draw up water from the water table by capillary action, as these samples of soil draw up water from the pan. One of the most important functions of the soil is here exemplified. Sometimes simple experiments like these show in tangible, concrete form, the results that may be expected from a farm practice that must be extended over a number of years in order to achieve these same results in the field.

CHAPTER V

THE BENEFITS OF TILLAGE

TILLAGE—stirring the soil—is the simplest and commonest operation on the farm. Possibly this is why it is understood the least. There are a hundred farmers who can explain perfectly the theory of a balanced ration to a dozen who know all the benefits of the ordinary soil-stirring that occupies their time more than any other farm practice. This is largely due to the fact that there are two perfectly obvious benefits of tillage —the ground must first be stirred to make a mellow seed bed, and it must be stirred to kill the weeds that dispute with the crops for possession of the land. The necessity for stirring the soil to accomplish these ends is so apparent that many have looked no further for the benefits of tillage than those that appear on the surface.

The Present Emphasis on Good Tillage.—During the past twenty-five years there has been a marked change in the attitude of farmers toward tillage. Probably no other farm operation has advanced farther in the quarter century, not only in a better understanding of its purpose, but also in the efficiency with which it is performed. During the last quarter of the ninteenth century emphasis was placed most emphatically on tillage—"good tillage," "thorough tillage," "better tillage," and similar captions were the subjects for more articles in farm papers and more talks at farmers' institutes than any other operation of farming. The results of this campaign, or "tillage era," as it has been called, are seen everywhere in better crops and more fertile fields. Just now we seem to be passing through a "humus era" in our agricultural development. The benefits of green manuring and cover crops are being heralded far and wide—perhaps over-emphasised a bit—as the benefits of tillage may have been overstated; for humus, as well as tillage, is only one of many factors that enter into the profitable production of crops. It is well, however, that each of the important points in good farming is before us so prominently for a time; it brings them to the attention of men who would not consider them so carefully were they not stated so emphatically and discussed so exclusively.

TILLAGE TO PREPARE THE SEED BED

The primary object of stirring the soil is to prepare it to receive the crop and to eliminate competition with other plants. In the wild, seeds are sown on untilled land and very few find a congenial seed bed and grow into lusty specimens of their kind. They may find the soil upon which they fall hard, cold and unresponsive, or already pre-empted by other plants of the same or other kinds. Even if the seeds germinate they at once engage in a life struggle with their neighbours for food, water, sunshine, a struggle that is relentless and inexorable. A very few plants, favoured by some accident in position, get a start over the others and slowly choke them to death, or keep them in wan and feeble subjection. Nature is satisfied, apparently, with small returns for her prodigal seed sowing; if one seed in a thousand brings forth fruit unto the harvest she is satisfied.

Man requires a larger increase. It is in his power to secure it in two ways; he can make the condition of the soil favourable for the germination of the seeds and the growth of the plants, and he can prevent competition by isolating his plants. All of these conditions are secured by tillage. The plow buries wild plants and loosens and deepens the soil; the harrow makes it mellow to receive the seed; the cultivator kills the weeds that would dispute with the crop for possession of the land. Simple as these statements are, they are fundamental truths.

An Improvement on Nature.—The farmer whose land yields the most increase is the one who improves upon Nature the most, in sowing seeds and in growing plants. He sows seed, not in Nature's haphazard way, wherever the wind blows, on good soil or poor, but only upon soil that is congenial for that plant and that has been specially prepared to receive it. He grows plants alone, not in a hand to hand struggle with other plants that he does not want. In fact, a man's success in farming is measured largely by his ability to remove from his plants the uncertainties and the competition that these plants would have to face were they growing in the wild. This result is accomplished largely by tillage.

Good tillage is especially needed in making the seed bed. The farmer who does the most harrowing is usually rewarded at harvest time far beyond the value of the time spent. All seeds need a mellow soil, a warm soil and a well ventilated soi' in order to germinate quickly and grow fast. Plowing and harrowing make the soil finer and secure these conditions; and the degree of mellowness, warmth, and aëration it has is governed very largely by the thoroughness with which the land is fitted. It is one of the common remarks at farmers' institutes that too little attention is paid to the "tillage of preparation," as it is sometimes called; that farmers content themselves with plowing and then harrowing the soil once or twice before seeding, when perhaps three or four harrowings and one or two turns with the clod crusher would have paid. Seeds will not germinate readily if they are placed between three or four large lumps of soil. No matter how moist the lumps are, the seeds dry out fast because they do not touch the soil on all sides. If the lumps are broken into fine soil and the seeds are planted in this, they have an even and constant supply of water. It is as impracticable and unprofitable to sow seeds upon lumps as to spread fertiliser upon lumps.

The number of times that it will pay to harrow when fitting a seed bed depends entirely upon its texture; a sandy loam soil may be as mellow and friable after one turn around the field as a clay loam is after three turns. Moreover it is impossible to make some soils mellow, even with a dozen harrowings. The trouble lies deeper—it may be lack of humus or poor drainage, which must be corrected in other ways. But up to a certain point tillage does fine, loosen, drain, aërate, and warm the soil and fit it for growing a profitable crop. Some soils respond to this tillage of preparation better than others; a good farmer soon finds out, by experimenting and observing, how thoroughly it pays to fit his land. He may be surprised to find that one or two extra turns with the harrow will pay him much more when harvest time comes than the cost of the labour.

TILLAGE TO KILL WEEDS

The second object of tilling—that of killing weeds—is forced upon the attention of the farmer with back-breaking and sweat-rolling regularity. A weed is a plant that is not wanted—whether it is a Canada thistle in the pasture, a daisy in the meadow, quack-grass in the corn or "pusley" in the garden. The plant may be innocent enough in itself, and may sometimes even be grown as a crop, as when sand vetch sown this year for hay comes up next year in the corn planted on the same land. A weed is a plant out of place, according to man's scheme, so he becomes its bitter enemy.

The Tirade Against Weeds.—From the amount of wordy abuse that weeds have to stand from man one would think that they are free moral agents and capable of choosing between the already overcrowded wildwood, where they would have to fight for a living, and the inviting farm lands where the soil has been made soft and comfortable. If one were to ask a thousand farmers in this country, "What is the greatest trouble you have in farming?" the complaint that would rise most readily to the lips of nine hundred of them would be "I could get along all right if it was not for those pesky weeds." Weed recipes, purporting to be short cuts to the extermination of this torment, are offered by the score. Many bulletins and several books on weeds keep constantly before him the danger of relaxing watchfulness against the great pest. It would almost seem, from all that is said about and against weeds, that if only those plants that we put into the soil could grow, and no others, the chief impediment to the farmer's prosperity would be removed and he could take a half holiday six times a week.

Friendly Words for Weeds.—In recent years there has grown up an entirely different attitude toward weeds on the part of some people. We are told that weeds are a great blessing, not a curse. The reason given is that if there were no weeds to kill, many farmers would not cultivate their soil; hence the other benefits of tillage—saving moisture and setting free plant food—would not be secured as often as they are now, when a multitude of weeds makes it necessary to till frequently. We have also been told that if a man cultivates his land as often as he ought, in order to secure these other benefits of tillage, weeds will not bother him much.

Here, then, are two extreme views concerning the warfare between man and weeds. One man says that all that it is necessary to do is to cultivate often enough to keep down weeds and the other benefits will be secured in so doing. The other man says that if the soil is tilled as it ought to be in order to save water all the weeds will be killed in so doing. Both are radicals. The fact is that sometimes the soil should be stirred when there are no weeds in sight; and sometimes weeds are so bad that the soil must be stirred two or three times as often as would be necessary were we considering only soil moisture and plant food. During a hot, muggy July, with heavy thunder storms about every other day, the hoed crops would not suffer for lack of water were it not for weeds. Purslane, ragweed, crab-grass and a host of other worthies luxuriate over the ground, choking and stifling the crop and pumping immense quantities of water from the soil.

The chief way in which weeds injure crops is by

34. TILLING THE SOIL—THE MOST COMMON, AND THE MOST IMPORTANT OPERATION ON THE FARM

It is a benefit to the soil and the crop in many ways

35. POTATOES IN DIRE NEED OF TILLAGE

Soil water is being lost rapidly, and the plants need it

36. POTATOES LUXURIATING UNDER A MULCH OF LOOSE, DRY SOIL

This preserves the moisture to them. This crop will "pan out"; the other will not robbing them of water. They do use some plant food, but the loss is not as great. These weeds must be killed, even if one has to use the cultivator twice as often as would be necessary otherwise. On the other hand there may come a dry August during which few weeds start, but it is very essential that the cultivator be run over the ground once or twice a week so as to keep a layer of loose dry soil between the precious soil moisture and the air which is hungry to suck it up. I have a little garden back of my house. During a rainy spring if I worked it enough to keep down all weeds it would be about three times a week, which is about three times oftener than it would be necessary to cultivate were soil moisture and plant food the chief concern. The question as to whether weeds or the saving of water, should be the guide to the frequency of tillage depends upon the locality and the season; it is as often one as the other.

Weeds a Spur to the Sluggard.—Weeds, are however, a mentor that we but half appreciate. It is easy to advise "Till as often as is necessary to keep soil water from escaping," but the escape of soil water is a very intangible thing, likewise the setting free of plant food, a benefit of tillage that will be mentioned shortly. We cannot see either of them, and most of us are apt to be careless about the things we cannot see. But weeds are very much in evidence. If the average man sees a dozen lusty pigweeds waving triumphantly above his early potatoes he will be much more likely to cultivate and hoe his garden than if he happens to notice that there is a thin, moisture-losing crust on the surface of the soil. Every good farmer has a big bump of pride which begins to thump impatiently when his crops get weedy, especially if they are close to the road. So he begins to stir the soil with a cultivator and to dig into it with a hoe; then the chief mission of weeds in farming has been accomplished. From the beginning of husbandry they have pricked men on to till the soil. Now we know of other reasons for keeping the soil stirred around our plants, reasons that are important enough to make the best farmers till when there are no weeds. But weeds will always remain the spur of the sluggard—and a fairly reliable tillage guide to the rest of us.

TILLAGE TO SAVE WATER

Aside from preparing the soil to receive the crop and killing the weeds that would compete with the crop, tillage accomplishes another result that may be even more valuable to the farmer. It saves soil water, as has been described in the preceeding chapter, by establishing a mulch, which makes it impossible for much water to evaporate. The amount of water that is saved by keeping the surface of the soil thoroughly stirred may be as much as one-third of the total amount that the soil receives. Snyder found that the soil of a corn field which had been cultivated frequently contained 17 per cent. of water in the layer of soil from 9 to 17 inches deep, while the same layer of soil in another part of the same field, but which had not been tilled, contained only 12 per cent. of water.

The efficiency of a soil mulch in preventing the escape of soil water needs no further proof than observation in orchard, field and garden. During a summer drought the corn leaves shrivel first where the farmer has cultivated least. Just beneath the loose dry soil of his cultivated field he finds moist soil, with plant roots revelling in it. On an uncultivated field he may have to dig down a foot or more before he finds moist soil. Even a casual examination of the farms in any community will convince a man that the operation which contributes most largely to success or failure in farming is tillage, chiefly in its relation to the saving of soil water.

Tillage to Increase the Water-holding Capacity of a Soil.—Besides saving water by surface tillage the farmer can increase the capacity of his soil to hold water by deep tillage, as by fall plowing and by subsoiling. These operations loosen the soil to a depth of 5 to 14 inches and thereby enable it to retain more of the water that falls upon it as rain or snow, a large part of which runs off as surface drainage when the soil is hard, carrying with it, perhaps, much fine soil. The shallow plowing so common in parts of the South is responsible for much of the loss of soil by washing in this region.

Heavy clay soils and other soils that are quite compact, so that they absorb water very slowly, are benefited by subsoiling and fall plowing. Soils containing a large amount of sand are not benefited by this treatment—they are already too loose. The methods of plowing and subsoiling are considered at length in the following chapter.

DRY FARMING

An important phase of tillage, in its relation to the saving of soil water, is the farm practice now commonly called "dry farming." In reality all farming that does not make use of irrigation is dry farming, but the term is commonly understood to mean the growing of crops in the arid or semi-arid regions without irrigation. In recent years much interest has been manifested in dry farming, and its methods have been applied with increasing success over a constantly widening territory. The sections where it is practised are chiefly eastern North Dakota, eastern South Dakota, western Kansas, western Oklahoma, central Texas, eastern Washington, eastern Oregon, and scattered areas in Idaho, California, Utah, Montana, Colorado, New Mexico, Wyoming and Arizona. These regions include approximately 300,000,000 acres. Nevada is said to be the only arid state in which dry farming cannot be practised successfully.

For the most part dry farming is practised on the border land of aridity, and on land in arid regions that it is impossible or impracticable to irrigate. There are many millions of acres of land in the arid and semi-arid regions that are above the "ditch line"; that is, they lie so high that the expense of bringing water to them would be greater than the returns. Of such a nature, for example, are the high bench lands in the Cache Valley, Utah. Moreover, the amount of water in the arid and semi-arid regions that is available for irrigation is sufficient to water but a small portion of the entire area. Dry farming is the only kind of farming possible on millions of acres of land in the West.

Dry farming is an attempt to grow the common crops with the minimum amount of moisture. Most of the sections in which it has been successful have a rainfall of from 10 to 15 inches, from 2 to 5 inches of which, and often more, is lost by drainage and seepage. Some dry farming sections have less than 10 inches of rainfall, yet crops are grown

37. WATER HELD BY A COARSE AND BY A FINE SOIL

The finer a soil is the more water it will hold. An abundance of soil water is as essential to the production of large crops as an abundance of plant food. Tillage makes a soil finer

38. A LUMPY SOIL

The soil in these lumps is useless to crops for the time being, as the root hairs feed only on the outside of small particles. Break up these lumps by wise tillage and by adding humus and so increase the "pasturage" of the crops

39. A PERFECT SOIL MULCH

It is five inches to moist soil. The surface layer of dry soil acts as a blanket

40. WHERE TROUBLESOME WEEDS ARE WONT TO CONGREGATE AND TO MULTIPLY

Keep the fence rows clean or, better yet, do away with them altogether. Many fences and walls are unnecessary that compare very favourably with those of Eastern farms that receive from 30 to 40 inches. Dry farming is never resorted to, however, except when irrigation is impossible or inexpedient. It is an illustration of what can be done by tillage to conserve soil water that every farmer in the humid East may consider with profit.

Dry Farming Methods.—The success of dry farming is based upon a most thorough application of the principles of tillage. Two things are essential: the subsoil must be put in condition to receive and hold all the water that falls upon it, and the surface soil must be made dry and mellow to prevent the escape of that water by evaporation. A third essential, in some cases, is to secure seeds that are adapted to these trying conditions.

In preparing the subsoil, an effort is usually made to leave it compact. Sometimes this is done with a special tool called a subsoil packer. This is a bevel wheel roller that follows the plow, rolling down and packing the subsoil. Each of its ten wheels has V-shaped rims which press deeply into the soil, compacting it below. The object is to make the subsoil so firm that the air spaces will be very small, hence air will not circulate freely through the soil and dry it out. The soil packer usually accompanies a steam plow outfit, which is generally used in dry farming. A weighted disk harrow, with disks set straight, is also used. The harrow is then put on—the same day if possible—and three or four inches of the surface soil is made into the most efficient kind of soil mulch, which is renewed frequently. Keep the harrowing close up to the plowing. The mulch established in dry farming would be a revelation to those Eastern farmers who barely scratch the surface of their fields, scarcely keeping down weeds, and who complain about drought.

The combination of tools sometimes used in dry farming is remarkable. Frequently one 32-horse-power traction engine will drag twelve 14-inch plows, two corrugated iron rollers, two clod crushers, besides harrows and seed drills, the whole making a long procession, with unbroken land in front and smooth and seeded land behind. Such an outfit prepares and seeds about 35 acres a day.

When the rainfall is very scanty it is necessary for success in dry farming to summer-fallow the land every other year. The object of the summer fallow is to store water for the next crop. Excellent tillage, together with packing the subsoil in some cases, is the simple and easy secret of dry farming. It is the application, in an almost perfect way, of a principle that has been known, but usually very imperfectly applied, for several hundred years.

Crops Under Dry Farming.—The crop grown most largely under dry farming is Durum or macaroni wheat. This was introduced into America from Russia by the United States Department of Agriculture about ten years ago and has proved a most valuable acquisition. In Russia it has been grown successfully for many years on the steppes, where the rainfall is less than 10 inches. The readiness with which this remarkable plant lends itself to dry farming, and the wonderful increase in its culture, is shown by the fact that the first large crop of macaroni wheat in the United States was harvested in 1901, while the crop of 1905 was close to 30,000,000 bushels. Average crops are 15 to 25 bushels of wheat per acre in the arid region regions, and 30 to 50 bushels in the semi-arid regions. It thrives only in a very dry climate.

Besides Durum wheat, Turkestan alfalfa, Kaffir corn, sorghum, emmer, dwarf milo maize, and a number of forage grasses are grown under dry farming. Rye and barley are also grown somewhat. It is important to sow less seed than in humid farming, 30 to 35 lbs. per acre is usually enough. This seed should be grown in semi-arid, not in humid, sections.

The present interest in dry farming in many parts of the West amounts to little less than a speculative fever. Dry farming companies are being organised to plant farms of 3,000 acres or larger. The values on "desert" land are appreciating rapidly, in some cases running from $2.50 to $50 an acre in two or three years. Undoubtedly dry farming is doing much and will do vastly more to reclaim land formerly considered worthless because of lack of water for irrigation. Next to irrigation it is the most important agricultural practice of our times in the arid West. Yet it is altogether likely that land will be used for dry farming which ought never to be cleared of sage brush. The present enthusiasm over dry farming bears some of the ear-marks of a boom. There are bound to be some disappointed and some ruined practitioners of dry farming, just as there were thousands of disappointed and ruined "rain-belters" in western Kansas, Nebraska, and the Dakotas twenty years ago. Undoubtedly the area that can be brought under profitable dry farming may be greatly extended, as better methods for husbanding scanty rainfall become more generally known and practised. But there is an unusual amount of risk connected with it, and no man should undertake this kind of farming until he has investigated it thoroughly. Whenever possible irrigation should be used to supplement dry farming.

TILLAGE TO PROMOTE FERTILITY

The longer a soil lies idle, so far as the farmer is concerned, but is covered with Nature's crops year by year, the richer it becomes. The chief reason for this is pointed out in Chapter XII. Nature's crops die, decay and are returned to the soil, adding to it what they have taken out and improving its texture; the farmer's crops are mostly removed. On the other hand, it is also true that tillage makes the soil more fertile. It will do so as long as the supply of humus that is in the soil when it is cleared for cropping is maintained, and provided as much plant food is added to the soil each year as is removed in crops. But since neither of these conditions are complied with, it usually happens that the longer the soil is tilled the poorer it gets. The falling off in its ability to produce crops would be very much greater, however, were it not for the food-producing power of tillage.

How Tillage Increases Fertility—The explanation of the power of tillage to increase fertility is very simple. In Chapter I it was stated that the chief agency that has broken up the rocks and made them into soil is weathering—the action of water, air, heat and cold. This action is still going on; soils are being weathered, as well as rocks and stones; their grains are becoming finer, their plant food more available. Tillage makes a soil more fertile chiefly because it loosens it, thus allowing a free entrance to these agencies that make it finer, and hence expose more surface for the roots to feed upon. Every time that a soil is plowed, harrowed or cultivated it is loosened, and air, water, heat and cold enter it more freely and attack it more vigorously. Nearly all farm soils, even some that produce poor crops, contain enormous quantities of plant food (Chapter XI), most of which, however, is in such a form that the plants cannot use it, being "unavailable" as the chemist says. Tillage makes much of this latent plant food available from year to year, by promoting better weathering.

Tillage mixes the soil grains and changes their relative positions so that certain particles are brought together that have been separated before, and there is greater likelihood of chemical changes. It may carry to the surface grains of soil that have been lying several inches deep for many years, thus exposing them to weathering. It fills the soil with air which hastens the decay of vegetation, thus making humus and a large amount of carbonic acid. This carbonic acid becomes a part of the soil water and greatly increases its power to dissolve plant food from the mineral portion of the soil. The better aëration of the soil due to tillage is favourable for the growth of the valuable nitrogen-fixing bacteria described on page 40. The activities of other beneficial germs in the soil are promoted by the warmth, drainage and aëration that follow tillage. If it were not for these beneficent effects of tillage soils would become "worn-out" much sooner than they do now from continued cropping with little return.

Tillage the "Poor Man's Manure."—Tillage has been called "the poor man's manure," with some fitness. Stirring the soil does enrich it to the extent that it enables the farmer to use more of the native plant food in the soil. But it is not a manure in the sense of plant food applied. The value of thorough tillage to increase fertility was first demonstrated about 1730 by a wise old English farmer, Jethro Tull. We read in his "Horse Hoeing Husbandry" that he planted wheat in rows far enough apart to allow tillage between them, and raised more profitable crops without adding manure than his neighbours, who manured highly but tilled little. In his enthusiasm Tull made the mistake of believing that tillage could take the place of fertilising, which we now know to be wrong. Good tillage—deep plowing, thorough harrowing, frequent cultivating—will largely reduce the fertiliser bill or delay the day when fertilisers and manures will be needed, because it enables the farmer to get the most from the soluble plant food already in the soil. But there always comes a time when tillage must be supplemented with manuring or fertilising. Tillage is not fertilising; but, if done thoroughly, it may save much fertilising.

THE ALCHEMY THAT FOLLOWS THE PLOW

Thus it is seen that simply stirring the soil, the commonest work on the farm and the work which often receives the least thought, sets at work many agencies that exert a profound influence on the productivity of the land. Every tiller of the soil should know something of the wonderful alchemy that follows the plowshare and cultivator tooth. As he plows, harrows, cultivates, rolls, drags, he should think, not that this is so much dirt that he must handle, so many weeds that he must kill, but that he is getting the soil laboratory ready for the delicate reactions and subtle changes that are a part of the wonderful process by which soil is made into plants. There is much more to tillage than burying trash, killing weeds and mellowing lumps. The farmer who sees only these things when he stirs the soil is not getting as much pleasure from his business as he might. As he trudges up and down the long field behind the sweating team, turning the moist earth into crumbling furrow slices, or guiding the cultivator between rows of thrifty plants, the work will seem less irksome if he thinks of these wonderful activities that he has set in motion, and plans how he may keep the soil laboratory in the best running order.

CHAPTER VI

THE OBJECTS AND METHODS OF PLOWING

PLOWING is of greater antiquity than any other tillage operation because it was found necessary to break ground so that seeds could be planted long before stirring the soil for other purposes was thought of. Four thousand years ago, and probably earlier, the plow was the chief and usually the only implement of tillage. The style of plow that was used at different periods in the history of the world is a very reliable index to the agricultural development of the time; just as to-day we gauge the ability of a farmer chiefly by the skill and thoroughess with which he handles the soil.

The Early Plows.—The primitive plow was a small tree having a small branch starting out from it in the form of the letter V. The trunk of this was the beam, and the branch, which was much shorter than the other and was sharpened, was the point. The beam and point were often braced by being tied together with a withe; a handle was made by lashing another branch to the beam. When this crude tool was dragged along the surface it scratched the ground to a depth of three or four inches—deep enough to allow seeds to be planted, which was considered the only reason for plowing in those days. This very unsatisfactory tool was replaced by wooden plows of various patterns, most of which simply stirred the soil, but did not invert it. Not till about the eleventh century were plows with iron points used to any extent. These plows were made by local blacksmiths in different localities and were thus extremely variable in style and in value, according to the skill of the blacksmith. Greater uniformity and a decided increase in the value of plows resulted from the discovery of how to make plowshares of cast iron, in 1785, and of case hardened or chilled shares, in 1803.

Early American Plows.—As late as the beginning of the nineteenth century the plow commonly used in this country was made mostly of wood, the mouldboard and point being partially protected by worn-out horseshoes and other scraps of iron that were nailed upon them. It was often about twelve feet long and required eight to ten oxen to draw it, and one man to ride upon the beam. A good cast iron plow had been made by Charles Newbald, an American farmer, and patented in 1797, but it never became popular solely because of the prejudice against the innovation. Farmers said that cast-iron plows "poisoned the land" and "caused weeds to grow." By 1810, however, most of the prejudice against iron plows had passed away and they came into common use. These early cast plows, however, were mostly made of one piece, and when the point was dulled the whole plow was useless. The next step was to provide interchangeable points so that the plow could be easily repaired.

It was not until near the middle of the last century that plow makers clearly comprehended the chief function of a plow—to pulverise the soil. Hitherto their efforts had been directed mainly toward making a plow that would invert the soil and so bury trash. The early plowshares had been broad, high and bent over at the top very little, so that they inverted the soil very neatly but did not crumble it much. It was soon seen that the only way to accomplish this end was to make the furrow slice twist as it turned over. Then was produced the modern broad, flat plowshare with overhanging mouldboard, which accomplishes this result admirably.

Subsequent to this discovery, during the last half of the nineteenth century improvements on the plow followed rapidly. The length of the beam and handles was increased and the latter set lower, thus making the plow much easier to control. The jointer, that most useful adjunct of the modern plow, was introduced and improved. One of the greatest troubles with the early plows was that they did not "scour" well; that is dirt collected on the mouldboard, making it rough and greatly reducing its efficiency and increasing the draft. The introduction of the Oliver chilled plow, in 1870, was a notable event in plow making.

About 1870 gang plows were introduced. The first gang plows were two or three plows fastened to one beam. These were very cumbersome and were soon superseded by the sulky gang plow, which is largely used to-day, especially in the West. Various methods of hardening the mouldboards of plows were tried, until carbonising or chilling came into general use for both steel and cast iron plows. Plow making has reached its highest development in America, from which plows are shipped to all parts of the world. There are about 9,000,000 plows in use on American farms, representing an investment of $80,000,000 for this tool alone.

The Modern Plow.—The modern plow is the

41. PLOWING THE CORN FIELD

Plowing is the most important tillage operation; upon it depends much of the success of the crop. Plow skilfully, not slovenly

42. FLAT-FURROW PLOWING—THE SLICE COMPLETELY INVERTED
Handsome, but does not crumble soil enough. Good for burying herbage

43. CLAY SOIL PLOWED WHEN TOO WET
Note the glazed appearance of the furrow-slice. This will make the soil cloddy

product of more than forty centuries of slow improvement. During this time it has developed from a crooked stick, which barely scratched the surface and served no other purpose than that of permitting the seed to be sown, to a tool that pulverises the soil, increases its water-holding capacity, adds to its fertility and has a more important influence on the productiveness of the land than any other single treatment that it receives. Many attempts have been made to introduce substitutes for the plow in preparing the soil for crops, but none have been uniformly successful, although various ingenious spading tools are of considerable utility in special cases.

The improvement of the plow and of plowing will continue. Where it is practicable for the farmer to use greater power, deeper working plows will be used, which will pulverise the soil to a much greater depth, thus increasing its water-holding capacity and its productivity. The fact that the plow—the most important tool of agriculture—was improved more during the nineteenth century than in all the centuries that precede, well illustrates the changed point of view, in this new era, when the best thought and the highest inventive genius of the world are being brought to bear upon the problems of the farmer. Two centuries ago this would not have been possible.

THE OBJECTS OF PLOWING

Aside from crumbling the soil, the chief objects of plowing are to destroy wild plants so that cultivated plants may be grown in their place; and to bury the trash, as corn stubble and potato vines, so that the soil may be made ready for a new crop.

A plow that does not accomplish both of these results is faulty. All refuse should be covered so deeply that it is not brought to the surface by the harrow. This can usually be done without completely inverting the furrow slice. A broad and deep furrow buries trash better than one that is narrow and shallow. If tall herbage is to be plowed under, as in plowing under a green manuring crop or a heavy growth of weeds, a chain with one end attached to the beam of the plow and the other to the end of the double-tree will make it easier to bury the plants, especially if a jointer is used also. Sometimes it is necessary to rake the coarsest part of the manure into the furrow in order to bury it completely. Herbage and refuse that is plowed under deeply decays more rapidly than if it is turned under with a shallow furrow, because the surface soil is dryer. When there is a large amount of herbage or trash to bury the team should be stronger and the furrow deeper than if the soil is unencumbered. If the furrow slice is completely inverted herbage and trash is buried best, but the soil is not pulverised much. It is possible to bury herbage and trash with a crumbling furrow.

Pulverising the Soil.—Unless a plow pulverises the soil so that the harrow can finish the process easily, it is not doing all that should be expected of it. Plows differ greatly in the way which they leave the furrow. The furrow-slice is sometimes completely inverted and lies flat on the bottom of the preceding furrow; this is called "flat-furrow plowing." Other furrows stand nearly edgewise without being crumbled much; this is called "overlapping-furrow plowing." Still others are broken to pieces entirely; this is called "rolling-furrow plowing."

The way in which the surface is left by a plow depends chiefly upon the style of the mouldboard that is used; the bolder or more overhanging it is the more completely is the furrow-slice broken. An overhanging mouldboard prevents the furrow-slice from turning flat and leaves it rough. A rolling furrow-slice buries herbage and trash about as well as a flat one if a jointer is used; and it crumbles the soil much better. A plow that turns this kind of furrow is the best for most conditions. Flat-furrow plowing is the handsomest but the poorest plowing, in most cases. The soil is not crumbled and, what is even more important, the least amount of surface is exposed to the air. It is also more difficult for the harrow teeth to take hold of the tips of these slices and break them without distributing the sod or herbage beneath. But flat-furrow plowing covers trash and herbage better than the other types of plowing, so that it may often be used to advantage for plowing stubble land, especially if it is fairly light.

Lap-furrow plowing, in which the furrow-slice is only partly inverted, being left on edge and partially overlapping the preceding furrow-slice, leaves the soil fairly well pulverised and with a ridge surface so that it is easily mellowed and fined by the harrow, but it does not bury trash or herbage well. It is especially valuable for fall plowing, particularly of clayey soils, as it leaves many air spaces beneath the furrow-slice and the soil is fully exposed to weathering.

It is well worth while to have two or three types of plows on hand and use each acording to the results it accomplishes and the purpose in view. This costs more, but greater efficiency results.

A very slight difference in the lines of the mouldboard may make wide results in plowing. Much depends upon the nature of the soil. Sandy soils may be plowed with a flat furrow-slice with much less detriment than clayey soils, which need much loosening and pulverising. If a tenacious soil is plowed so that the furrow-slice is completely inverted it is much heavier and colder, for the season at least, than if the furrow-slices were overlapped.

Plowing to Prepare the Seed-bed.—It is expensive work fitting soil to receive the seed. Plowing usually represents less than one-half the cost of preparing land for the crop; harrowing, dragging, planking, etc. if well done, cost more. One of the objects in plowing, then, should be to leave the soil in such a condition that as little subsequent tillage as possible will be needed to fit the land for the crop. This means that the plowman should not be satisfied with the handsome flat-furrow plowing that took prizes at the agricultural fairs 50 years ago, but which requires much expensive harrowing to make it mellow. He should turn a furrow-slice that is just as loose and crumbly as possible and still bury the trash, so that the labour of harrowing may be reduced. The kind of plow that should be used, and the condition in which the land should be left, depends upon the kind of soil and the crop to be grown upon it; but whenever a plow is purchased its ability to pulverise the soil should be the chief measure of its value.

Plowing to Promote Fertility.—It does this by all the ways mentioned in the previous chapter. It exposes the soil to weathering more completely so that more of its insoluble plant food is made available. It lets in the air which corrodes the minerals, forms carbonic acid with the humus and enters into many chemical and physical combinations that have an important influence on soil fertility. Deep plowing brings to the surface subsoil that has not lost so much of its plant food as the surface soil, not having been weathered so completely. After one or two seasons this rich, raw soil becomes weathered sufficiently and is then utilised by crops. Furthermore, the mere fining of the soil by plowing increases its fertility by presenting a large surface for the roots to feed upon. The work of the nitrogen-fixing germs and of other useful agencies that make for fertility is wonderfully hastened by the warmth and aëration induced by plowing. It is chiefly the depth to which the plow stirs soil that gives it preëminence among tillage tools.

Plowing to Deepen the Soil Reservoir.—Plowing may be made the means of increasing the water-holding capacity of a soil. Soils of a close texture, as the clays and clay loams, may be made to hold more water by deep plowing, because rain will sink into the loosened soil better. But sandy soils should not be plowed deeply; they are too leachy at best. Light soils through which water passes too readily may be made somewhat more retentive by plowing them at the same depth every year. The tramping of the horses and the weight of the plow tend to compact the soil at the bottom of the furrow, making a kind of artificial hard-pan, or "plow bed," which checks the downward passage of water somewhat. The depth at which this hard-pan should be formed is six to eight inches, depending upon the rooting habits of the crop grown. On the other hand, in plowing heavy soils the aim should be to prevent the formation of the hard-pan by varying the depth from year to year. The benefit of deep plowing to prevent the washing of clay soils is pointed out in a following paragraph.

Plowing to Drain the Soil.—Plowing may also be made the means of draining a soil. It is best to have a soil of such texture that all water falling on it will be absorbed or pass through it. But this is rarely possible, particularly when the soil is heavy. Such soils, especially if nearly level, may often be plowed into "lands" to advantage. The dead furrows may be in the same place for several consecutive seasons, thus throwing the soil into slightly elevated beds. Lands from 15 to 30 feet wide are often used, but lands 60 to 75 feet wide drain the soil more efficiently, because not enough water may flow into narrow dead-furrows to make sufficient current to carry it off. Even when the field is fairly well drained, naturally or artificially, it is best to leave dead furrows from 30 to 50 feet apart, though not in the same place for succeeding years.

Plowing to Establish a Mulch.—In addition to its value for increasing the capacity of a soil to hold water, plowing is one of the best means of preventing the evaporation of water already in the soil. King, who has made many noteworthy experiments on this subject, concludes "In the conservation of soil moisture by tillage there is no way of developing a mulch more effective than that which is produced by a tool working in the manner of a plow, to completely remove a layer of soil and lay it down again, bottom side up, in a loose condition."

HOW DEEP TO PLOW

There is sometimes much discussion about how deep the soil should be plowed. It is as impossible to answer this question definitely and conclusively for all farmers as it is to prescribe that corn should be planted the first week in June everywhere. The best depth for plowing depends upon conditions; these each farmer must study for himself. No general statement can be made ; "plow deep" is sound advice in many cases, and very bad advice in others.

The depth to plow should be governed mainly by the nature of the soil. As a general rule, the heavier the soil the deeper it should be plowed, for heavy soils need the loosening, draining and aërating effect of deep plowing. Such soils are commonly plowed from seven to ten inches deep. On the contrary, the lighter the soils the more shallow should they be plowed, since deep plowing makes the soil looser, and it is already too loose and leachy. If, however, humus is being plowed under, as manure or a cover crop, the plowing can be deeper. Sandy soils are commonly plowed four or five inches deep. If, however, it is desired to form an artificial hard-pan on such soils they may be plowed deeper. On raw soils it is well to plow about half an inch deeper each year until a depth of nine or ten inches is reached.

The depth to plow should be influenced by the feeding habit of the crop to be grown. Are its feeding roots mostly in the first foot of soil or in the first five feet? Plowing for fruit trees and root crops should be deeper, as a rule, than for other farm crops.

Plow somewhat deeper in midsummer and fall, when the soil is apt to be dry, than in spring when the soil is cold and wet. In the humid sections farm manures or green manures plowed under at that time decay quicker near the surface than eight or nine inches deep. If the soil is damp and it is desired to dry and warm it for an early planting, say of corn, it should be plowed more shallow than ordinarily. This is not advocating shallow plowing for heavy lands in general, but stating what may be done in certain cold, wet and late seasons.

Eight inches may be considered deep plowing for many soils; rarely is it practicable to plow more than eleven inches deep. Most field crops feed much more deeply than is commonly realised. Corn, parsnips and sweet potato roots occupy the ground to a depth of four or five feet and may go several feet deeper, depending upon the nature of the subsoil. It is safe to say that, on an average, the roots of field crops forage five to six feet deep. But most of the feeding roots are in the plowed ground, because this is the richest, warmest and the best ventilated part of the soil. Therefore, the deeper the soil is plowed, within certain limits, the greater will be the productivity, because more of this congenial pasturage is provided for the roots.

Subsoiling.—The subsoil sets a limit to the depth at which certain soils can be plowed. It may be yellow or of a different nature than the surface mould, and contain a large amount of raw plant food. If much of this raw soil is mixed with the surface soil the productivity of the land is apt to be seriously reduced for a number of years, or until weathering has acted upon the subsoil brought to the surface. About 1850 there was a widespread discussion in this country on the advantage of deep plowing. It led to the introduction of an implement with two plows upon one beam; a small one which turned a furrow three or four inches deep followed by a larger one which ran six

44. IDEAL PLOWING

The soil is pulverised and herbage buried. The harrow can now fit this soil very easily

45. AN IDEAL PLOW FOR ORDINARY WORK

This is the plow used in Fig. 44. Note the lines of the mouldboard, the angle of the handles, and the jointer, beam wheel, and clevis

46. A CHEAP AND RATHER INEFFECTIVE WOODEN-BEAM PLOW

Compare mouldboard with preceding and note absence of overhang. Too shallow-working for any work but furrowing out for planting or eight inches deeper, turning its furrow-slice upon that of the smaller plow. These plows proved impracticable, chiefly because they left the raw subsoil on top of the ground and buried the rich surface soil at the bottom of the furrow.

The introduction of the subsoil plow, a little later, remedied this fault. This follows the plow and stirs the soil in the bottom of the furrow to a depth of five to ten inches, but does not bring it to the surface. There are two types of subsoil plows. One is shaped something like a harrow tooth; the other consists of a wedge-like shoe on the lower end of the bar. There is much difference of opinion concerning the value of the subsoil plow in general farming. It is not used nearly as much as it was fifteen years ago. The general conclusion seems to be that it is of service only on the heavier soils, which need better aëration and need to be deepened. But the soil that is loosened by the subsoil plow quickly falls back and becomes compact again, so subsoiling affords only temporary relief. Moreover, subsoiling may be a positive injury to some soils by destroying the earthworm burrows that effectively aërate and drain the subsoil.

The lessened appreciation of the subsoil plow in recent years is due largely to the more general practice of under-drainage. Under-drainage loosens, deepens and aërates the soil permanently and to a much greater depth than subsoiling. Subsoiling should follow, not precede, under-drainage. It augments every good effect of drainage. At present the use of the subsoil plow is confined mostly to fairly well-drained lands which have a hard and dry subsoil; and for breaking up a hard-pan that is close to the surface. Subsoiling is usually injurious to a wet, clayey soil, making it puddle. It is practised chiefly for crops that have long roots, notably for parsnips and carrots. The cost of subsoiling is from $1.50 to $3.00 per acre, or fully as much as the cost of plowing. It is customary to subsoil about every third or fourth year.

Deeper Plowing Desirable.—The probability is that the future improvements in plows will be largely along the line of increasing the width and depth of the furrow without adding much to the draft. The farmers of a century hence will stir the soil deeper than we do, and so have more of it directly under their control. But many farmers of to-day do not plow nearly so deeply as they might and ought. This is especially true in the South, where the one-negro-one-mule-one-plow combination is thought to be the best solution of the problem. One mule can hardly furnish power to turn even four or five inches of soil. A large proportion of the Southern soils are clay, especially in Tennessee, Georgia, Alabama and Mississippi. These clayey soils, being very fine grained, absorb water very slowly. Hence, if they are not loosened and deepened by deep plowing the rains quickly overflow them and the surface drainage washes away the fine, rich soil and the fertility of the land with it. There are other causes of this washing (see Chapter XI), but shallow plowing is now and has long been one of the principal causes.

Farmers in other parts of the country are losing nearly as much by persisting in the old-time shallow plowing of four or five inches, when they might easily double the feeding pasturage of their crops. Many of the farmers of the western prairies, in Nebraska, Dakota and contiguous states, plow very shallow. Sometimes the land is plowed only three to four inches deep—sometimes it is not plowed at all for a year or two, the surface being simply scratched sufficiently to cover the seeds. When the tough prairie sod was first broken in the pioneer days, about seventy-five years ago, it was necessary to plow very shallow. The great "prairie breaker" of those days had a beam nine to ten feet long, was pulled by eight to twelve yoke of oxen, and turned a furrow 18 inches to two feet wide and not more than 2 or 3 inches deep. This served its purpose admirably, but as soon as the native grasses were subdued it was seen that deeper working plows were needed. Shallow-working "sod plows" are still used for subduing sod. Prairie soils are so open in texture and rich to such a depth that deep plowing does not give the beneficial results that it does in many other parts of the country. But it is quite certain that in the long run it pays to plow these soils deeper than the mere surface scratching that is now given to many of them.

DRAFT IN PLOWING

The power that it takes to plow, and the amount of draft required, have an important influence on the depth of plowing and the amount of pulverisation accomplished. Experiments by Anderson showed that it takes 55 per cent. of the total draft in plowing to cut the furrow slice, and 12 per cent. to turn it; the 33 per cent. remaining is used in the friction of the sole and the landslide. An old share point makes plowing as hard work for three horses as a new point does for two. The use of a bold mouldboard increases the draft very slightly, not over 2 or 3 per cent. more than when a straighter mouldboard is used. This is a small price to pay for the much greater efficiency of the bold mouldboard.

A plow not adjusted properly may require 50 per cent. more energy to move it. The investigation of Sanborn, in 1888, showed that the use of a coulter or jointer increases the draft and the use of a beam wheel decreases the draft. He also found that the deeper a plow works, the less draft it requires in proportion to the size of the furrow-slice. That is, it does not take twice as much power to turn a furrow 8 inches deep as to turn one 4 inches deep, but less than this—about 10 per cent. for each additional inch in depth, according to results at the Utica Plow Trial in 1867. Likewise the wider the furrow the less power is required in proportion to the soil turned. With a bold mouldboard a furrow may be turned two or three times as wide as it is deep; if the mouldboard is less overhanging it is necessary to turn narrow furrows in order to leave the soil in good shape.

Heavy Teams Do Better Work.—It is a mistake to plow with a light team, and nothing but the most shallow and least efficient plowing can be done with a single horse or mule. A light draft not only makes the plowing more shallow than if a heavy team were attached to the same plow, but the plow works in a jerky manner, and it is harder for both team and man. Roberts says: "If the little plow turning a furrow only nine or ten inches in width and six inches deep could be exchanged for a plow capable of handling a furrow sixteen inches wide and ten inches deep; and the two 900 pound horses replaced by three of 1,200 each, the necessity for subsoiling would be obviated and the cost of plowing diminished rather than

47. SHIFTLESS PLOWING IN NORTH FLORIDA

The land is plowed only where the rows of the crop are to go; after the crop is growing the farmer "breaks out the middles"

48. A TURNING UNDER THICK HERBAGE WITH THE AID OF A CHAIN

One end is fastened to the beam, the other to the doubletree

49. THE APPEARANCE OF LAND AFTER FALL PLOWING

Soils that "puddle" should not be plowed in the fall

50. THE APPEARANCE OF THE SAME LAND THE FOLLOWING SPRING

The soil has been weathered and the texture improved. Fall plowing also promotes earliness increased, wherever the fields are large and fairly level. The larger team could get through three acres while the smaller is getting through two; thus, by adding one-half more to the daily cost of the team, without any increased expense for plowman, half as many acres again will be turned, and much better."

Horses that walk fast are better than a slow team, not only because they cover more ground, but also because they do better work; the faster the plow moves, provided there are no obstructions, the better is the soil pulverised. Large level fields are plowed better and quicker with a two or a three shore gang plow and four to six horses than if the power is divided into three teams pulling three single plows; and the saving of plowmen is worth considering in these times when farm help is scarce. A still greater concentration of power is commonly practised in the West, where it is not uncommon to see fifteen or twenty horses pulling a single gang plow. When two or more teams are used on one plow the doubletrees of the forward teams are chained to the ring of the neck-yoke of the beam team.

The Power for Plowing.—Next to the style of plow, the kind and quality of the motive power is the chief factor that controls the depth and thoroughness of plowing. In America the ox, horse and mule are used almost exclusively, being the cheapest. Traction engines are quite frequently used in the West, especially in the arid and semi-arid regions. In many cases steam power has not been as satisfactory as horse power, because it costs more—horse flesh is cheap in this country. In Europe, where horses are dearer and machinery cheaper, steam power is often more practicable.

Either a traction engine or a stationary engine is used. The former is run back and forth across the field dragging behind it a gang plow with six to twelve plows. A 25-horse-power engine is commonly used. A steam plow outfit complete costs from $2,000 to $4,000. It is run by two men and plowing usually costs about 50 cents an acre as against 75 cents to $1 by team. The stationary engine runs the gang plow by means of wire cables. The traction engine has been found more practicable in this country than the stationary engine, but the latter is used more commonly in Europe. There, too, electricity is used as a power for plowing. Some German fields are plowed with power secured from an electric trolley which is stretched above the field, giving, it is claimed, a cheaper and more satisfactory power than steam.

Steam, electricity or any other machinery power will not become a very important feature in American plowing for many years to come, except in the West. It is solely a question of economics—what kind of power is cheapest. Horses and mules are the cheapest power at present on the majority of American farms. We would naturally expect that machine power will first become practicable in this country where farming is done on a very large scale, and where the land is sufficiently level to make machine plowing feasible. The great farms of the western plains furnish these conditions and here steam plows are becoming common. However, in view of the recent astonishing developments in farm machinery, it would not be surprising to see within a quarter of a century some kind of a small power plow adapted for the farmer who tills less than a hundred acres. One can even imagine the small farmer of fifty years hence riding over his field in a sort of automobile plow and handling it with brake and lever. There have been more remarkable improvements than this within a generation. But certain New England fields, at any rate, will never be plowed with an automobile plow unless the rocks in it weather with remarkable rapidity during the next few decades. It is more than likely that a willing team of Clyde or Percheron horses and a skilful man guiding the handles of a good walking plow, will be, for many years, the cheapest and most effective method of getting the soil ready for a crop on 90 per cent. of American farms.

THE ESSENTIALS OF A GOOD PLOW

There are many styles and makes of plows, each different from the others in some respect. The kind of plow that should be bought depends upon the use for it and upon the way it is built. Do not buy a plow by its name or the reputation of the firm, any more than you would buy fertiliser by brand or a cow by pedigree. The essential parts of a good plow are briefly discussed below:

The Beam. This may be of iron, steel or wood. A wooden beam is cheaper and lighter than a metal beam; for these reasons a majority of the plows now found on farms have wooden beams. Walnut and ash make the strongest plow beams. Steel beams, which are much lighter than iron beams, are rapidly replacing wooden beams, being much stronger.

The Mouldboard is the most important part of a plow; its shape should be studied carefully by a plow buyer, so as to note how it will lift, turn and pulverise the soil. The general shape of the mouldboard should be spiral. This most important principle in the construction of the mouldboard was first stated clearly in 1839 by two plow makers, Samuel Witherow and David Pierce. "The main object is to pulverise the soil, and the only way in which it can be effected is by bending a furrow-slice on a curved surface forward so that it shall be twisted, somewhat in the manner of a screw." The more nearly spiral a mouldboard is, the more completely will the soil be inverted, but it is not pulverised to any extent.

The extent to which the mouldboard pulverises depends mostly on the steepness of its upward curve and the abruptness of its outward curve; that is, the upper or rear end is curved more sharply than the lower or forward end. This "bold mouldboard," as it is called, draws slightly harder and clogs a little more than those having a more moderate curve, but its much greater effectiveness in pulverising the soil more than compensates for these objections. The abrupt mouldboard is adapted for nearly all plowing, except for the fall plowing of clayey soils and for breaking new land, when a plow having a long and gradually sloping mouldboard is more effective.

The Coulter, or cutter, may be in the form of a knife or a rolling disk. The disk coulter is usually more useful than the knife coulter, which clogs easily. It is especially serviceable for plowing under litter, as cornstalks and straw, which it rolls down and cuts. The jointer, however, is now used more for this purpose.

The Jointer, or skim coulter, is a most serviceable attachment, especially when stubble, grass or manure are to be turned under. When herbage is plowed under without a jointer there is likely to be a line of it left between the furrows. It skims a shallow furrow and deposits the herbage in the bottom of the furrow where it is covered by the furrow-slice of the mouldboard. It also pulverises the soil, if set deep enough to keep the furrow-slice from turning too flat. Both coulter and jointer increase the draft and should be kept sharp.

The Beam Wheel, or truck, which is attached to the end of the beam, is useful simply for steadying the plow. It should not be used to regulate the depth of the furrow, for if it is set low in order to make the plow turn a shallow furrow, it acts as a brake. If it is used merely to make the plow run more steady by reducing the effect of the motion of the horses, whiffletrees and eveners, it reduces the draft to a considerable extent.

The Share, or plow-point, cuts the bottom of the furrow-slice from the land. It should be kept sharp, especially if grass or other roots are to be cut. The draft of a plow with a dull share is about 7 per cent. greater than the draft of a plow with a sharp share. Shares may be renewed or sharpened.

The Clevis, or bridle, is the metal attachment at the end of the beam used to regulate the depth and width of the furrows. The hitch on the clevis is raised to increase and lowered to decrease the depth; the clevis is swung to the right to increase width and swung to the left to reduce it. The clevis on swivel plows is changed by a lever from the handle. With some plows the change is effected by moving the beam at the handles. Some plows have only notches in the clevis for holding the draft ring. There is a double clevis in use.

In brief, the characteristics of a good plow are these: It should be as light as is consistent with desired strength. It should run steadily and have as light a draft as possible. It should pulverise the soil as well as turn it.

WHEN TO PLOW

Most plowing is done either in early spring, just before the planting of the crop, or late in the fall. The chief factor that decides this question is that of convenience. The best time to plow, however, depends upon the climate, the soil and the crop, as well as upon the convenience of the farmer. It is not necessarily the same for adjacent farms.

Fall Plowing.—Land is plowed in the fall chiefly in two cases; to improve its texture and to prepare it for fall seeding. Clayey soils, if not liable to puddle, are benefited most because it exposes them to weathering. Sandy soils may be greatly injured by fall plowing, because they are already too leachy. Where there is danger of washing from plowing clayey soils in the fall Roberts recommends that single furrows be drawn across the field about four or five feet apart; as, for example, between rows of corn. These improve the soil by weathering, make it earlier and it does not run together or puddle. These furrows are easily levelled in spring with a scantling chained crosswise under the front end of the harrow, and driven lengthwise of the furrow. This makes more work, but it pays on cold, wet clays. It should never be practised on any soils that wash badly during the winter.

Fall plowing is practised more in growing wheat and other cereals, and in market gardening, than for other crops. It is an almost universal practice in many sections of the West. It should be done early, when the ground is fairly dry. An incidental advantage of fall plowing, in some cases, is that it destroys wire-worms. Land for fall seeding should be plowed, if possible, two or three weeks before sowing. Lap-furrow plowing is preferable. Land plowed in the fall may be benefited by being plowed again in the spring before being seeded; but usually a good disking is sufficient.

The Spring Plowing.—Spring plowing should be done early, before the days when a hot sun and drying wind suck from the unplowed soil much of the water that the crop could use to great advantage. A soil may lose as much as twenty tons of water per acre weekly by being left unplowed late into the spring. This is equal to 1.75 inches of rainfall. Early plowing also dries and warms the surface soil so that it may be planted early. Furthermore, the earlier soil is plowed, the more spring rain it catches. If the land is covered with a catch crop there are additional reasons for plowing it early; the herbage will decay better, and if the catch crop is one that lives over the winter, as rye, it will be prevented from reducing the supply of water in the soil by its spring growth. The popular rule "Plow as early in spring as the ground works up mellow" epitomises the experience of many generations of farmers.

The exact time to plow in spring depends mostly on the wetness of the soil. If the soil is light and porous it may be plowed, oftentimes, two or three weeks earlier than heavy soil on the same farm. Not till the soil crumbles readily when turned up in the furrow-slice is it in the best condition for plowing. If it is turned over in clods there will be trouble. The texture of a clayey soil may be nearly ruined by plowing it once or twice when it is wet; the soil is thrown into great clods which it may take several years to mellow. There is always a tendency to plow heavy soils too early, when they are wet, since early plowing means so much to the success of the grains which thrive best upon these soils. On the other hand, it is equally unprofitable to plow when the soil is very dry, as such a soil is likely to be puddled by rains when the lumps have been pulverised by the harrow. In both fall and spring plowing it is always better to plow a week or more before seeding so as to allow the loose soil to settle, thus increasing its ability to supply film water to the seed.

WHEN PLOWING IS DISPENSED WITH

In a few sections of the country, especially in the Southeastern States, some farmers have a way of plowing only one or more furrows where each row is to be. The crop is then planted and the ground between the rows is plowed later. This "breaking out the middles" is a back-handed way of plowing, for the soil cannot be plowed and fitted nearly as conveniently and thoroughly after the crop is started as when the land is unoccupied. The only excuse for this practice is a rush of work at planting time, and it is doubtful if even this ought to be valid.

There are occasions when it is best not to plow at all. If a mellow seed bed can be prepared readily without plowing, and the surface soil is plenty rich enough, the land may be simply harrowed deeply in the spring and sown to the grains, which prefer a compact soil beneath the surface. Farmers in the prairie states sometimes follow this plan. Sometimes land from which beans or other crops have been removed is harrowed in preparation for fall seeding of grain. These cases, however, are very rare, as compared with the almost universal experience that thorough plowing is the best preparation of a seed bed.

USEFULNESS OF THE DIFFERENT KINDS OF PLOWS

There are a number of distinct types of plows, each of which is adapted for certain conditions. Furthermore, there are many makes or brands of each class of plows and these differ widely in construction and in value. The merits of the five most important classes of plows—landslide, swivel, sulky, disk and gang—will be discussed briefly. When it comes to choosing between the different makes of the same type of plow, the buyer must scrutinise the construction of each, especially the mouldboard, as advised in preceding paragraphs.

The Landside Plow is the oldest and most common type of plow. Probably five-sixths of all the plows used in the country belong to this class. It turns a furrow only in one direction, usually to the right; and more perfectly than swivel plows, which turn the furrow in either direction. It leaves a dead-furrow, which is no disadvantage on most land, as it assists in drainage.

The Swivel Plow is constructed so that a furrow may be turned to the right or to the left, thus making it possible to plow a field so that all the furrows are turned one way and no dead-furrows are left. It is especially adapted for plowing hillsides, because it leaves no dead-furrow to collect water. For this reason it is sometimes called the hillside plow. For general purposes, however, it is not usually considered quite as efficient as a landside plow.

The Sulky Plow is a plow mounted on wheels, with provision for the driver to ride and to control it with a lever. The plow itself may be a swivel, which is turned at the end of each furrow; or there may be two landside plows, one turning the furrow-slice to the right and the other to the left, these being used alternately so that the plowing is back and forth, not around the field, and no dead-furrows are left. The landside construction is usually considered somewhat superior to the swivel construction in sulky plows.

Under ordinary conditions the draft of a sulky plow is no greater than the draft of a landside plow doing the same amount and quality of work. A large part of the weight of the plow falls upon the axles, so that the friction on the sole of the plow is greatly relieved. A sulky plow weighing three or four times as much as a landside plow does not pull any harder, even with a man mounted upon it. If the soil is soft, so that the sulky wheels sink into it or clog, the draft is increased. Two heavy horses can pull it, but three are better. A good sulky plow, properly adjusted, should turn as even and deep a furrow as a landside plow, and somewhat wider. If the soil is hard or rooty, it keeps in the ground better than a landside plow. This type of plow is of service only on comparatively level land; it is not practicable on hilly and rocky land. The mechanism of a sulky plow is not difficult to operate nor does it get out of order easily. Wherever it can be used to advantage the sulky plow saves the time and strength of the plowman; it is being used more every year by American farmers.

The Gang Plow differs from the sulky plow chiefly in the fact that it turns more than one furrow at a time. From two to twelve plows are mounted upon a frame, all turning furrows the same way, one following another. The sulky gang plow provides a seat for a man; others have handles, like a landside plow, and are guided by the plowman. The latter commonly have two to four plows, run on low wheels. Some of the largest gang plows are reversible, like a sulky plow; they have two gangs, one right hand and one left hand.

Gang plows are practicable only where there is a large area of fairly level land to be plowed. In this country they are used chiefly for plowing in the West. The chief saving that they effect is in decreasing the number of plowmen and in getting a larger area plowed when the weather and soil are suitable. Power is furnished by horses, mules, or steam, principally by horses but frequently by steam in this country. A steam gang plow, combined with a seeder and harrow has reduced the time required for manual labour in plowing, seeding and harrowing, in the production of a bushel of wheat, from 38.8 minutes in 1830 to 2.2 minutes at the present time; and the cost of human and animal labour for the same operations, from four cents to one cent per bushel. It takes from six to eight horses to handle a four-furrow gang plow. When adjusted right a gang plow should do as good work as a sulky or landside plow. It is probable that they will be used to an increasing extent in this country, especially in the West; but the sulky plow is better adapted for average conditions in the East.

Disk Plow.—This implement is beginning to be used quite extensively in arid and semi-arid farming. It consists of a tempered steel disk, either single or in gangs of two or more, which is 25 to 30 inches in diameter and set at an angle to the surface of the soil, so as to invert and pulverise it. The disk is kept from clogging by an adjustable scraper. It is mounted on wheels and provided with levers, as in a sulky plow. The disk plow is commonly used with steam power. It is especially valuable for hard, sticky soils, and has been found most practicable in "dry farming" in the West. It does not appear that it will supplant the mouldboard plow in the East, but it can be used to advantage in humid regions for breaking up the "plow bed" or "plow sole" formed by plowing heavy land with a mouldboard plow at the same depth for several years.

ADJUSTING THE PLOW IN THE FIELD

A good plow, handled or adjusted improperly, is no better than a poor tool. The same implement can do first-class plowing and very poor plowing, according to the skill of the man who holds it. When a plow is taken to the field the first thing to do is to adjust it properly—the adjustment varies with the team, the type of soil and the object sought. It pays to spend some little time in getting a plow adjusted right.

Professor W. P. Brooks gives the novice at plowing some excellent suggestions on this subject; they are here condensed, and slightly modified: Hitch the team as close to the plow as possible and hitch to the lowest hole in the clevis. Start the plow and note whether the furrow is sufficiently deep; if not, hitch higher one hole at a time until the plow cuts at the right depth. If the furrow-slice is turned over flat, and a lap or rolling furrow is desired, it may be because the furrow is too wide in proportion to its depth; to correct this, the clevis must be moved to the left. If the furrow stands too nearly on edge it is narrow in proportion to its depth; move the clevis to the right. A plow that is properly adjusted should run in the soil for some distance without being held, cutting a furrow of even depth and width, provided the soil is free from stones and other obstructions. If it will not do this either the plow is a poor one, or, what is more likely, it is not correctly set up or adjusted. When it runs all right, lower the beam wheel until it just touches the surface. Thus adjusted the plow will do its best work as easily as it can be made to run.

CHAPTER VII

HARROWING AND CULTIVATING

EVEN the best plowing is but the beginning of good tillage. Unless followed by thorough harrowing and, for crops planted in in rows or drills, by thorough cultivation, the harvest is likely to suffer. The necessary tillage subsequent to plowing is of two kinds. The first is fitting the land to receive the seed, by harrowing, rolling, planking, brushing, etc. This tillage before the crop is planted, together with plowing itself, is sometimes called "the tillage of preparation." After the crop is planted the only kind of tillage needed is cultivating, called "the tillage of conservation," because its chief function is to save, or conserve, the soil water. This distinction is made to emphasise one very important fact; that if the tillage of preparation is judicious and thorough, the tillage of conservation will be easy and effective. The best cultivating cannot atone for hasty and imperfect harrowing. Many of the tools used for harrowing are equally valuable, in a modified form, for cultivating, since the main object of both is the same—to stir and fine the surface soil.

OBJECTS OF HARROWING

The plow leaves the soil in a rough condition, too rough and hard, in most cases, for planting. Some light sandy soils are so completely pulverised and levelled by good plowing that they are sometimes seeded without being harrowed, but this practice is rarely profitable. The plowed ground must be loosened and pulverised so that the seeds will touch moist grains of soil on all sides, instead of lying between clods and lumps. The chief object of harrowing, then, is to make a fine and mellow seed-bed. In so doing it increases fertility, prevents the evaporation of soil water, makes the soil warmer and accomplishes all the other benefits of tillage. That the harrow teeth fertilise and water the soil as well as fine it, is a figure of speech that is based upon realities in the field. Harrowing may also be a means of covering the seed and of killing weeds.

Better Harrowing Needed.—The necessity for harrowing more thoroughly than is commonly done needs to be repeated and reëmphasised. Some farmers are content with one or two harrowings, or merely enough to break up the largest lumps and enable the seeds to germinate. But that is not enough. We harrow to increase the feeding area of the roots all through the season by giving them finely divided soil in which to spread. We harrow to put the soil in the best possible condition to catch and hold the rains. We harrow to warm the soil, to aërate it and to promote the activity of the germ life that is so essential to its fertility. This means that the ground should be gone over more than is necessary to merely break up the lumps so that the seeds will germinate. It means harrowing and cross-harrowing, three times, four times, six times if necessary; or until all of the upper four or five inches of soil upturned by the plow has been made as nearly like an onion bed in mellowness as the texture of the soil will permit.

It does not pay to skimp harrowing in the rush of the busiest season of the farmers' busy year. A farmer once told me that every time he went over a certain piece of land with his cutaway harrow, in preparing it for corn, he received more than seventy-five cents an hour for the work when the ears were bushelled. Of course there is a limit, for every soil, to the number of times that it will pay to harrow it. Eight harrowings might give a larger crop than three harrowings, but would the increase be enough to justify the expenditure? It is worth while for every farmer to find the point where better tillage ceases to be profitable on his soil. When he ascertains this he will be surprised to find how far this limit is beyond the common practice of the neighbourhood.

KINDS OF HARROWS AND USEFULNESS OF EACH

Harrowing tools are of innumerable patterns. Most any ingenious farmer can make a harrow that will do good work. There used to be a great many home-made harrows and cultivators, but now the patent implements are so reasonable in price and superior in efficiency that it scarcely pays to get one made by the local blacksmith.

All harrows and cultivators are of four general types. The first class, represented by the spike-tooth harrow, press the soil down while pulverising it. The second class, represented by the spring-tooth harrow, lift the soil while pulverising it. The third class, represented by the Acme harrow, slice the soil and lift and turn it somewhat. The fourth class, represented by the cutaway, roll over and cut the soil. There are

51. THE WORK OF THE ACME HARROW

It slices, pulverises and inverts the soil. It is one of the best tools for fitting land, especially if alternated, with the planker, as in this case

52. A HOME-MADE SPIKE-TOOTH HARROW, IN TWO SECTIONS

This type of harrow is unexcelled for putting on the finishing touches in fitting land. It is not efficient on a stony or soddy soil

53. A SULKY HARROW

The middle teeth can be removed so that the implement will straddle a row of plants. It then becomes a cultivator numerous variations of and gradations between these four types.

Some soils are benefited most by a type of harrow which may be almost valueless for other soils near-by; hence we have farmers who would not use any other harrow than a cutaway and spike-tooth, because these especially suit the soil on their farms. They even dispute with neighbours who have a different kind of soil and who think nothing is equal to a spading harrow and an Acme. Moreover, they may be growing a different kind of a crop, which may mean that a different preparation of the soil is needed. The fact is there is no best harrow any more than there is a best plow or best breed of cows. The best harrow is the one that prepares a particular soil for a particular crop most satisfactorily; and soils and crops differ about as much as the farmers that handle them. The farmer should experiment with several types of harrows and find the best for his purpose.

The Spike-tooth Harrow is a most efficient tool under certain well-defined conditions. There are more home-made spike-tooth harrows on American farms than any other tillage tool. Some of the older home-made spike-tooth harrows are square, but more commonly they are A-shaped, with teeth set vertically on the side pieces only and a horseshoe nailed to the nose for a chain ring. These harrows did imperfect work as compared with the spike-tooth harrows of the present time.

Recent improvements in this time-honoured tool have greatly increased its usefulness. These are the addition of many more teeth; providing that they may be adjusted to run either vertical or slanted backward at various degrees; and making the harrow in several sections, which facilitates cleaning the teeth of entangled weeds. The implement is now made with a steel or iron frame, usually rectangular, and should be provided with a shoe. The more the teeth slant backward the more shallow do they work and the greater is the smoothing effect of the tool. The teeth should be set straight only when it is desired that they work deeply and tear up the soil.

The size of the spike-tooth harrow varies from a single six-foot section to the forty-foot wide smoothing harrow of many sections that is used on prairie grain fields. The latter are drawn by four to six horses and cover thirty to forty acres a day. The width of all harrows has increased in recent years and is still increasing in obedience to the same demand that has given us gang plows. The wider a harrow is the steadier it runs.

Usefulness of the Spike-tooth Harrow—The spike-tooth harrow is seldom used now to tear up rough-plowed ground, as it was some years ago before improved harrows were available. The old time spike-tooth harrow had a few long, heavy teeth which tore up sod quite effectively, especially when weighted with rocks, or provided with a platform for the driver. At the present time most spike-tooth harrows are of the type called "smoothing harrows," having numerous small and short teeth. When the teeth are so short that the bar in which they are set scrapes the ground when it is in use, the implement is often called a "drag." This type of harrow is chiefly valuable for one purpose—to put the finishing touches on a piece of land that needs to be made very mellow and very level for seeding. It is usually preceded by a stronger and deeper-working tool, as a disk or spring-tooth harrow.

54. A SPRING-TOOTH HARROW

The depth at which it works is regulated by the levers. It is often made larger than this. The same tool is used as an orchard cultivator

55. THE WORK OF A SPRING-TOOTH HARROW

It is particularly serviceable for loosening a compact soil, as the teeth pull up, and is a valuable tool on stony, cloddy, and soddy land. It is often desirable, however, to level off the high ridges left by a spring-tooth harrow

56. "SWEEPS" ATTACHED TO A PLOW-STOCK, FOR "LAYING BY" CORN

They cut off large weeds, but injure roots and leave the soil ridged

57. THE EFFECT OF USING THE ABOVE TOOL FOR CULTIVATING A COTTON FIELD

Note the high ridges from which much water evaporates, and the deep furrows which favour the washing away of fine soil

A second occasion when a spike-tooth harrow may be used to advantage is in tilling a crop before it has come up, or even afterwards. Land in corn or potatoes, for example, may be run over a few days after planting with a shallow-working spike-tooth harrow with the teeth slanted backward; this will kill the young weeds and check the escape of moisture. This kind of tillage can be repeated to advantage every few days until the plants are two or three inches high, or until they are bruised by passing between the teeth.

The spike-tooth harrow presses down into the soil and compacts it more than most other harrows. It has something of the effect of a roller. For this reason it is somewhat more useful on light, sandy soils which need compacting, than upon heavy soils, although its compacting effect is not sufficiently injurious to warrant its being discarded for finishing and smoothing the heavier soils.

Spring-tooth Harrow.—The curved spring teeth of this popular tool enable it to clear obstructions easily; for this reason it is especially valuable on stony, rooty or stumpy land. The teeth can be set by a lever to run at various depths; this also affects the quality of the work done. The spring-tooth harrow leaves the soil in ridges of considerable height, which is a disadvantage in many cases, as it causes the soil to lose more water from the greater surface exposed to evaporation. This objection may be overcome by following it with a smoothing harrow. A section of smoothing harrow is frequently attached behind the spring-tooth harrow, or a joist or plank, say 2 inches by 6 inches, or a heavy iron pipe may drag behind it. Any one of these devices is quite successful in levelling the ridges left by the broad teeth.

The spring-tooth harrow is a good implement for rough work, and especially for stony ground. It is very popular for orchard tillage, partly because the teeth spring over the roots with little damage to them. It is not so serviceable when sod, green manure, or a large quantity of strawy manure has been plowed under, as the teeth are likely to dig out part of this material and leave it on the surface.

On rough land the spring-tooth harrow is jerky and hard upon the horses' shoulders. The draft of a spring-tooth harrow set moderately deep is about equal to the draft in plowing, but it is easier for a team to plow all day than to pull a spring-tooth harrow all day, because the plow runs more evenly. The jerkiness of the common type of this harrow—in which all the weight rests upon the teeth—is largely overcome in a more recent form, which is mounted on wheels. All the weight of this implement rests upon the wheels, thus allowing the teeth to pull up and loosen the soil, and relieving somewhat the unevenness in draft. Even the common type of spring-tooth harrow, however, leaves the soil lighter than most other harrows because of the upward pull of the teeth. It is this advantage, as well as durability and the ease with which obstructions are cleared, that makes the spring-tooth harrow so popular. It can be bought by sections in various sizes; the wider it is, within reasonable limits, the cheaper will the harrowing be done.

Acme Harrow.—This is the most noted representative of a type of implements known as the coulter harrows, so called because they have teeth that have been twisted, somewhat resembling a plow coulter. The teeth first cut the soil, then raise, turn and pulverise it, doing the work of a plow on a small scale. It has been stated that the plow makes the best mulch to prevent the escape of soil water. The great efficiency of the Acme and similar harrows rests upon their application of the cutting, raising and pulverising action of a plow. In the judgment of many people the Acme harrow will give satisfaction over a wider range of conditions than any other type. It will work from one to four inches deep, as is desired. Following the plow it breaks up the furrows as well as any other tool unless the land is rocky or the sod tough, in which case a disk or spring-tooth harrow is better. It leaves the soil nearly as level and mellow as a smoothing harrow.

Rolling Harrows.—Harrows of this class have one or more revolving shafts to which are attached a number of disks, which are either entire, as in the common disk harrow, or notched, as in the spading and cutaway harrows. These harrows work deeper than harrows of any other class. They are especially valuable for working heavy soil, tough sod and intractable land of any sort. Two things decrease their value for establishing a soil mulch—they leave the soil in rather high ridges, which evaporate much moisture; and, if not adjusted properly, the disks do not stir all the surface, but leave a triangle or cone of unstirred soil. The ridges may be levelled by dragging a section of a smoothing harrow or a heavy joist behind, but the draft on harrows of this type is heavy enough without this additional burden; it is somewhat greater than a plow, in most soils.

Usually the disk, cutaway and spading harrows should be used only to do the rough work of fitting the land; to tear it and bring it up to the point where an Acme or smoothing harrow can be used to advantage. They are sometimes used as a substitute for the plow, when deep tillage is not necessary or is not practicable; as to tear up the sod in an old orchard that it is proposed to cultivate, or to fit land for fall wheat after a crop of beans has been harvested. Some Western farmers fit the land in spring for the cereals, using one of these harrows which can stir the ground 5 inches deep.

The great trouble with any one of these rolling harrows, in the hands of a careless workman, is that the disks will be so set that they plow out wide, deep groves, leaving untouched ridges between them, which are lightly covered with loose soil. In order to completely stir the soil and establish an efficient mulch the disks should be set so that they will enter the soil at a wide angle. Rolling harrows are made in two sections or gangs and the gangs throw dirt in opposite directions, usually from the centre outward. This makes it necessary to overlap in order to keep the ground level, but a better way is to level it with a smoothing harrow.

The comparative merits of the three leading rolling harrows—the disk, cutaway and spading—is the subject of much needless dispute. Some farmers are partisans for one and some for another, according to the way it strikes their fancy or the way it works on their soils. In general they handle the soil in about the same way. Probably the disk harrow is used more than the other two at the present time, partly because it is less likely to break. The Meeker harrow, which is used by many market gardeners and truck farmers, is essentially the same as the disk harrow, except that it has many very small disks permanently fixed in a rectangular frame, instead of a few large ones. It leaves the soil about as smooth as an iron rake and is used solely for preparing a very level seed-bed.

WHEN SOIL IS READY TO HARROW

In harrowing, as well as in plowing, there is a good deal in catching the soil at the right time. If the land is inclined to be wet and the upturned furrows have a glazed appearance it is well to let them dry before harrowing. Several hours, or even several days, may be needed to bring them to that stage of dryness when the soil will crumble nicely. No other consideration should influence one to harrow before this. It is better to lose some of the water in this soil by evaporation than to run any risk of injuring its texture. On the other hand, if the soil turns over mellow and ready to be harrowed at once the time to catch it is right then, before it becomes dry on top. A delay of a single day in harrowing a plowed field may mean that half an inch or more of the precious water in it has been lost. After the furrows have dried out considerably they may become hard and cloddy and will be pulverised with greater difficulty.

The soil should be moist, not wet or dry, in order to do the most effective harrowing. Some of the lighter soils dry out very quickly in the furrow, even in an hour or two. If it can be done without too much inconvenience it is best to harrow these soils within a few hours after they are plowed—certainly the same day. When but one team is plowing on a light soil it will pay to take it off the plow and hitch it to the harrow early enough to make a mellow seed bed of the furrow-slices before nightfall. This is much better than to defer harrowing until the plowing is finished. The subsoil is compacted in harrowing; this starts capillary action and water is drawn from the soil below, and would escape were it not for the mulch of fine soil left on the surface by the harrow. The compacting effect on the subsoil by harrowing is a benefit on most soils.

LEADING TYPES OF CULTIVATORS

As the term is commonly used, a cultivator is any toothed implement that is used to stir the soil after it has been fitted, chiefly for the purpose of killing weeds and preventing the loss of soil water. Many harrows are used as cultivators under certain conditions; as when a spring-tooth harrow is used to preserve the soil mulch in an orchard, or when a spike-tooth harrow is used to run over the potato field when the sprouts are still small enough to slip between the teeth without injury. When narrowed down to its most distinctive usage a cultivator is a toothed implement drawn by one horse and used for inter-tillage, or for preserving the mulch between rows of plants. Most of these kinds of cultivators, however, are only small harrows with handles attached, and they stir the soil in about the same way as the harrows that have been described. All kinds of cultivators are sometimes called "horse hoes," but this name seems to be especially fitted for the broad-tooth coulter cultivators.

The following classes of cultivators include most of those in common use, but there is an almost endless variation in the details of construction in each class.

Shovel-tooth or Coulter Cultivators.—Probably more of the cultivators used in this country belong to this class than to any other. The teeth of different cultivators vary greatly in shape and size; nearly all enter the ground at an angle and are rounded on the front side. Many coulter cultivators work up the soil like a plow, lifting, turning and pulverising it to some extent. The soil is loosened to a depth of two to five inches, depending upon the style of cultivator and upon the adjustment of the lever with which many coulter cultivators are provided. The surface of the soil is left either quite level or in rather high ridges, depending upon the width of the teeth. The wider they are the rougher they leave the soil.

Cultivators with about five broad teeth work the ground deeply and are especially valuable for loosening heavy or compact soil; but for the purpose of killing weeds or preserving a mulch, a cultivator with more and narrower teeth is much better. There are too many broad-toothed, deep-working cultivators used and too few narrow-toothed shallow-working tools. Each kind is most useful for a certain definite purpose; the one for loosening a hard soil, as after planting or after a beating rain; the other for preserving the shallow mulch that is the most useful and economical kind of tillage during the summer. Various attachments accompany coulter cultivators, such as wings for hilling or ridging, and rolling disks to cut off strawberry runners.

Spike-tooth Cultivators.—Implements of this class have become very popular in recent years, and deservedly so. The spike-tooth cultivator is simply a spike-tooth harrow, shaped like an A, with handles attached. It may be worked shallow and leave the surface very level; for this reason it is considered one of the best tools for preserving the soil mulch after it has been made by deeper working tools. The teeth may be straight on one end and bent forward on the other and it should be easy to reverse the ends. The bent end works deeper. Most makes are also provided with a lever to regulate the depth at which the teeth work. The spike-tooth cultivator is not a good implement for killing weeds except when they are less than half an inch high. It is preëminently a tool for making a mulch. If weeds get a start the broader teeth of the coulter cultivator will uproot them much better.

The advantage of using a spike-tooth harrow as a cultivator for stirring the entire surface of the soil, where corn, potatoes, peas, beets and many other crops have been planted, has already been alluded to. Many people are afraid to use this harrow for this purpose, thinking it will pull up the crop as well as the weeds. But little if any injury to the crop results from this harrowing, chiefly because the seeds of the crop have been planted deeply and the soil firmed around them; while the weed seeds are mostly on or near the surface; hence young weeds have a much slighter hold upon the soil than the crop. The harrow may be used for cultivating these crops until they are four to six inches high; it is the most economical cultivating that can be given.

Spring-tooth Cultivators, usually with five teeth, are occasionally used. Like spring-tooth harrows, they work deeply, loosening the soil for four or five inches if necessary. For this reason they are quite serviceable on the heavier soils. But the superior value of shallow cultivation has been demonstrated so conclusively that it is doubtful if the spring-tooth cultivator has any advantages over the more common coulter cultivator and spike-tooth cultivator, except for the specific purpose of loosening a hard soil. It is not as efficient a weed killer as the coulter type of tool.

Sulky Cultivators.—Probably 90 per cent. of the cultivators used in the United States are walking coulter or spike-tooth tools, or some gradation between the two. Sulky or riding cultivators are used principally in the "corn belt" of the Mississippi Valley and are seen occasionally in the East. In most of them the teeth are in two gangs with a space between for the row of corn or other plants. Two horses are used, one walking on one side of the row and the other on the opposite side, the cultivator wheels straddling the row and the teeth working on both sides of it. Sulky cultivators nearly all have coulter teeth, but a few have spike teeth, spring teeth or even disks. The coulter teeth are preferable in most cases. Disks are apt to work too deep close to the rows. Disk cultivators are excellent, however, for chopping up and destroying large weeds, if the crop gets very foul. Several different sets of shovels are usually provided, including extra shovels which may be attached so as to run where the row space is left, thus making a sulky harrow which stirs soil for its full width and is used to prepare the soil for planting.

The chief advantages of a sulky cultivator are that it covers more ground than a walking implement and saves the strength of the farmer. But it does not do as good work, as a rule, since it is impossible to guide it so carefully. It always damages the young plants more than a walking cultivator, even when the very serviceable plant guard attachment is used on each side of the row to prevent dirt from being thrown against the young plants. Moreover, a sulky cultivator is considerably harder to draw than a walking cultivator.

Weeders.—The essential principle of all the several kinds of weeders is one or more rows of long, flexible teeth which stir the ground a good deal like the teeth of a horse rake; not being curved at the lower end, they do not stir it deeply. The teeth are either round or flat. The more common weeders stir a section of soil from six to nine feet wide; there are also adjustable weeders in two sections which stir from two and one-half to seven and one-half feet of soil.

Weeders are useful for three purposes—to kill very young weeds; to preserve a shallow mulch after the soil has been loosened by a deeper working tool; and to cover broadcasted seed. They are used chiefly for stirring the entire surface of the ground that has been planted to row crops, as corn, potatoes, parsnips and market-garden crops in general, doing the same work as the smoothing harrow, but not stirring the soil so deeply. The teeth tear up and kill tiny weeds just appearing on the surface, but since the crop plants are anchored firmly in the soil by deeper roots they readily pass between the flexible teeth without injury.

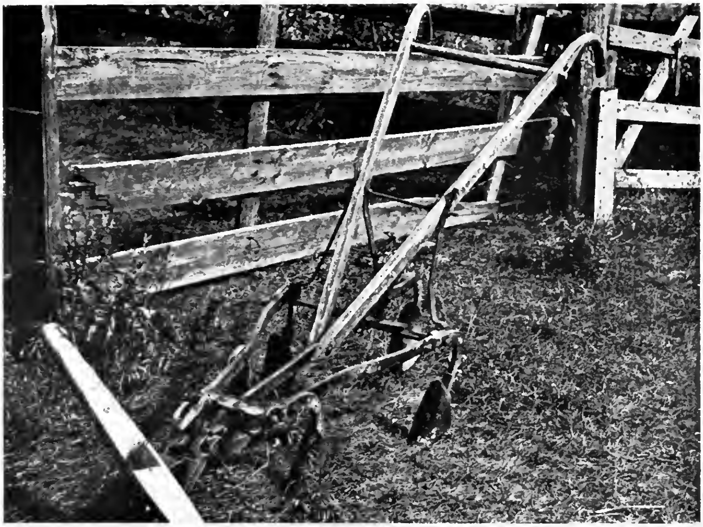
A weeder is not effective unless it is used very frequently, or often enough to prevent any weeds from getting sufficiently large to resist the teeth. It cannot be used successfully on stony soil. In some sections, and especially in market gardens, weeders are used very extensively; some truckers do most of their tillage with them up to the time when the plants get too large to pass between the long teeth without bruising. Since the weeder stirs the soil no more than an inch and a half to two inches deep, it should be supplemented with the cultivator whenever the soil gets hard. This is especially true on the heavier soils, which are apt to get caked beneath the very shallow mulch made by the weeder. The weeder is a special purpose tool, as compared with the coulter cultivator, which is a general purpose tool. It is most useful in growing crops under intensive culture and on soils of the best texture.

CULTIVATING TO KILL WEEDS

How often to cultivate depends upon the nature of the soil, the kind of crop, the dryness of the season, the prevalence of weeds, etc. It is a local and personal problem. This much is certain; one should cultivate often enough to keep down weeds, at least during the early part of the season. This advice would appear to be superfluous were it not that so many farmers do not keep down weeds.

Weeds injure the plants and reduce the yield in several ways. They crowd and shade the plants, thus keeping part of the life-giving sunshine away from them, making them spindling, like forest pines which are drawn up to a great height in their desperate struggle with each other to get light. They steal food from the plants. Every young corn plant that is being choked above ground by the tops of weeds is also being jostled below by their roots. These are in every inch of soil that the corn roots have penetrated, disputing with them for its richness. There are many figures on the amount of plant foods removed from the soil by various crops, but how about the amount of plant food taken out of the soil by a big crop of weeds in a potato field? It is true that the weeds are plowed under eventually, so that the plant food they use is not lost to the soil; but it is lost to that particular crop, anyhow, and the crop would have been bigger if the plants could have had the use of all the surface richness that the shallow-feeding weeds have gobbled up. I like to see a farmer stop his cultivator, even on his way to dinner, to pull up a particularly lusty and arrogant weed. He knows it is robbing him. The insidious drain that weeds make upon the most available fertility of our fields is not appreciated half as much as it ought to be.

Weeds Steal Water.—Weeds rob the plants of water as well as of food. They use as much and sometimes more water than cultivated plants in proportion to their size and weight. It is in this way that they inflict the greatest injury to crops. The plant food they use is restored to the land, and perhaps the crop of another year may use it, but the water they use is lost; most of it passes off into the air through their leaves. There are figures on how much soil water is used in growing a crop of corn or potatoes; how much water is used in growing a big crop of weeds between the corn or potatoes? Perhaps not so much, but certainly nearly as much. Where soil moisture is as important as it is in most parts of the country the



58. THE MOST COMMON TYPE OF DEEP-WORKING COULTER-TOOTH CULTIVATOR

It is excellent for breaking a crust and loosening a hard soil, but a shallow-working tool with narrower teeth is better for making a mulch

59. YOUNG CORN IN NEED OF A CULTIVATION

This crust, formed by a beating rain, is evaporating water. It should be pulverised into a mulch

60. A CULTIVATOR THAT IS REALLY A PLOW

Usually it is unwise to "plow out" corn in this way, unless the soil gets very hard. Plow deeply in spring, fit the land thoroughly, and cultivate shallow thereafter

61. CULTIVATING AT A DISADVANTAGE

The rows of corn that cross this steep North Carolina hill must be cultivated skilfully to prevent washing Note that rows are nearly level farmer can ill afford to spare water, even to grow weeds that will enrich his soil when plowed under. He had better grow plants to plow under in late fall, after the crop has ceased to need much water.

This advice is unnecessary for the majority of farmers, who hate a weed and understand how much it works against their interests. But some farmers appear to have gotten so accustomed to having weeds in their fields that they have come to view them with greater leniency, even with toleration. Weeds, like the poor, are always with us; we are liable to grow indifferent to both.

Cultivation is the greatest weed-killing device yet known, at least for crops that permit of intertillage. Some people are always looking for some new or patent way of getting rid of weeds with little labour, but no good substitute for cultivation has yet been found. In making the earth yield her increase nothing can take the place of stirring the soil. Most weeds are annuals; these are shallow rooted and are easily uptorn by the cultivator teeth. Some, however, are perennials and deeper rooted. These may require special treatment, such as rotation of crops.

THE BEST TIME TO KILL WEEDS

In cultivating to kill weeds it makes a difference what stage they are in. The vulnerable stages of most weeds are immediately after they have sprouted, and when they are in flower. Some perennial weeds, especially pasture weeds, may be killed best when in flower; but the sprouting stage is the time to attack most weeds on cultivated land. Weed seeds are mostly in the first inch or two of soil; a very shallow cultivation will expose the sprouting seeds and young weeds to the merciless sun. Many of the finer-seeded kinds are buried so deeply by a deep-working cultivator that they never come up again, especially if a coulter cultivator is used. It is easy to kill weeds in this way, but it is difficult to kill them after they are so large that cultivator teeth do not uproot them, and cultivating must be supplemented by hoeing and hand-pulling.

There is no better illustration of the old adage "a stitch in time saves nine" than in the killing of weeds. It pays to be forehanded in cultivating more than any other work on the farm. The time to start the cultivator is when the ground is covered with tiny weeds, just appearing above the surface, whether it has been six days or sixteen days since the last tillage. A delay of three or four days, or until the young weeds get their roots established two or three inches deep, means that many of them will not be uprooted by the cultivator. That is the beginning of a foul field. The profit in growing ordinary farm crops depends largely upon the farmer's ability to do as much of the work as possible with horse labour, which is cheap, and as little as possible with manual labour, which is dear. Many farmers have demonstrated that it is easier and cheaper to kill weeds with the cultivator than to let many of them grow large and then be obliged to hoe and pull them. More cultivations are necessary, but less hoeings.

When Weeds Get a Start.—Weeds are most apt to get a start during the interval between the time that the crop is planted and when it is up. The season may be cold and backward, and ten days or two weeks may intervene. At the end of this time ground which was mellow and weedless when planted is covered with a dense mat of small weeds. Most of these can be worked out with a cultivator, but some of them are already rooted so firmly that the cultivator teeth do not uproot them. From this beginning may be traced the growth of many a weedy field. In recent years farmers and gardeners have come to appreciate more fully the advantages of harrowing the soil once or twice before the crop is up. Weeders are also used; in small home gardens an iron rake answers very well. In this way the crop starts off clean instead of foul. Where freedom from weeds is as important as it is in growing onions the rows are sometimes marked by sowing a few radish seeds with the onions; these sprout long before the onions and show where the scuffle hoe can go before the onions are up.

When the crop is "laid by," or after the last cultivation, is another dangerous time for the propagation of weeds. The cultivation of many crops is stopped in early or mid-summer, either because the tops are so large that it would injure them to crowd between the rows with a cultivator, as for potatoes; or because it benefits the plant to grow more slowly during the latter part of the season, as for fruits. This period of relaxation on the part of the farmer becomes the busy season of some weeds. They crowd in beneath the crop and get so firmly established that many of them are on hand to bother the farmer after the next spring plowing. If perennial weeds are allowed to make leaves at any time during the summer or fall they are likely to appear again next spring. There are two ways of handling this difficulty: one is to keep the weeds cut out with a hoe during the latter part of the season; the other is to sow some catch crop at the time of the last cultivation, to catch and use the leaching plant food and water, to keep the soil from washing and to crowd out weeds. Both are worth being considered by the man who wishes to keep his farm clean.

Weed Collectors.—There are other ways of helping to keep down weeds besides cultivation. One of the most important is to change the crop, which is discussed fully under rotation of crops in Chapter XI. Another is to keep fence rows, corners, pastures and all waste places about the farm clean. The fence row around the field is often full of the very weeds that the farmer is fighting by cultivation. Never allow bad weeds to go to seed in these places; mow them frequently. A much better plan, however, is to dispense with the fence, and other weed-catching obstructions, as much as possible. Fences and walls are unsightly and they are a nuisance unless they serve the necessary purpose of keeping out stock.

There are many more fences in this country than there is any need of, especially in the older Eastern States. Riding over certain parts of New England, one would think that the farmers of a generation or two ago put in most of their spare time building stone walls, so checker-boarded is the country with them. Of course the stones had to be picked off the land, but surely there was a cheaper way of disposing of them than by laying them up into walls five feet high and three feet thick, around every two or three acres of the farm; to say nothing of the amount of land thus covered and made useless. It is good to see the present reaction from fence and wall building

No more of them are being built now than are needed to confine stock, and portable fences are being used more and more. This adds much to the sightliness and convenience of the farm and much, also, to its freedom from weeds.

The Prevalence of Weeds in Sown Crops.—Weeds are most apt to overrun a place when crops are grown that permit of no cultivation. Witness for example, the devastation of the Canada thistle, Russian thistle, devil's paint brush, etc., in the grain fields of the Mississippi Valley. Professor I. P. Roberts says, "It is believed that the time is not far distant when wheat, oats, barley, and indeed all grains that are now broadcasted or drilled, will receive inter-cultural tillage similar to that now given to maize (corn), and this will not be by hand, as in some portions of Europe, but by horse-hoe tillage." This time is a long way off in America, where tillable land is abundant and cheap, but undoubtedly the drift is in that direction—fewer plants per acre, more tillage, larger yields. When the cereals, now more grievously affected with weeds than hoed crops, are brought under this system of culture, they will be relieved from weeds by the magic that lies in cultivator teeth. Over three centuries ago quaint Thomas Tusser expressed one of the most important facts in the agriculture of his times, and of ours, in the couplet:

"Good tilth brings seeds,
Ill tilture, weeds."

CULTIVATION TO SAVE WATER

In the humid sections of our country, if the season is fairly wet one does not need to worry much about cultivating to save water early in the season.

If he cultivates as often as the weeds poke themselves above ground, which they do with astonishing alacrity and in countless numbers after each tillage, he will have established the best kind of a water-saving mulch. This is especially true in a wet May, and most especially true in a muggy, thundery July, when "pusley" starts up from the ground and grows a foot long in a single night, so it seems to our disheartened eyes. But there are times when cultivation is necessary and profitable, when we have few if any weeds to spur us to the exertion. This is apt to be the case during a summer drought when the soil is dried out several inches deep and the weed seeds in the surface soil cannot get moisture enough even to germinate. There are few if any sections of the country where it is not necessary at some time, during an average season, to cultivate for the explicit and sole purpose of preventing the loss of soil water. One season, however, may be so wet that the cultivation that prevents weediness is all that is necessary; the next season may be so dry that the cry of the crop is continuous and loud for more water, rather than for less weeds.

Signs of the Need of Cultivation to Save Water.—It is not difficult to tell when it will pay to cultivate, even when there are not enough weeds to justify it on that score. One has only to examine the surface soil. If it is hard, baked, cracked, or even if it has only a thin crust, there is work to be done. Soil water passes off rapidly into the air only so long as the surface soil is compact. If this is loosened the water cannot creep readily from grain to grain, and so is held below the layer of loose soil.

The first aim of the cultivator, then, especially when his plants are trying to weather a dry season should always be to keep a few inches of loose soil on top of the ground. When it gets compacted again, as it always does after a while, loosen it again, weeds or no weeds. Eventually the loosened soil falls back into place and becomes compacted again by its own weight; but one slight rain will make more of a crust over it than two weeks of settling. That is why it is more difficult to preserve a soil mulch in humid regions than in the semi-arid sections of the West. Where there is no rain whatever during three or four months of the growing season there is not much difficulty in making and keeping a most efficient dust mulch. In the East, where the cultivation of one day may lose half its value because of a slight shower the following night, it is a more tedious job. However, the Western man needs a better mulch—he has much less water to use and has to guard it jealously.

How Often to Cultivate.—There can be no rule as to the frequency of cultivation for saving water except this: cultivate often enough to keep the surface soil at least fairly mellow and free from crust. To do this may take eight cultivations one year and twelve the next year, on the same field. An adjoining field, with soil having a greater capacity to hold water, may give equal results from half as much tillage.

The reliable guides are the way the crops grow and the condition of the soil. When the corn leaves begin to curl in the heat of the day, when the lower leaves of the peas begin to shrivel and droop, when the potatoes look dispirited and the sugar beets droopy, the time has come for some energetic work. If the ground is hard, loosen it deeply with a shovel-tooth cultivator and smooth it off with a spike-tooth cultivator afterward. Repeat this with the latter tool often enough to keep a mulch over the roots of the plants that will preserve the coolness and water that have been lost to them before. The results of a few extra cultivations in a dry season, as seen in the corn bin or cotton basket, are sufficient to convert any man to the wisdom of mulch-tillage, even when weed-tillage is not needed.

HOW DEEP TO CULTIVATE

Within ten or fifteen years there has been a very decided movement in favour of shallow cultivation. Experiments have shown quite conclusively that there is as much value, so far as preventing the escape of water is concerned, in two or three inches of loose, surface soil as in four or five inches. This pre-supposes, of course, that the tillage of preparation—plowing and harrowing—has been thorough and timely so that the soil is loosened deeply and pulverised completely. The result has been that many of the old-fashioned, deep-working, hard-pulling and root-cutting cultivators have been relegated to the junk heap, and the shallow-working coulter and spike-tooth cultivators occupy their place in the tool shed. We do not hear so much about "plowing out" crops as formerly—they are cultivated. There are still many unwieldy, plow-like cultivators in use, especially in the cotton belt, but they are fast disappearing.

If the soil has been thoroughly loosened and pulverised before the crop is planted there is no need of stirring it more than three inches deep, at the most, after that. Aside from the energy lost in increased draft, deep cultivation is wasteful of soil water, because it brings to the surface a large amount of moist soil which soon becomes dry. The moisture in this soil might better have been left below where it could have been used by plants. Moreover, a deep-working cultivator leaves the soil in ridges, thus exposing more surface for evaporation; for some water is lost from the soil even when it is covered with the very best mulch. Furthermore, the valleys made by deep cultivation are the beginning of erosion.

Deep cultivation may cut many of the feeding roots of the crop. The roots of plants naturally seek the richest part of the soil. The soil near the surface usually contains the most plant food, because so much soluble plant food has been left there by the evaporation of soil water, and because the surface soil contains more humus, more germ life, more air and more of everything that makes for fertility.

In all ordinary soils the largest proportion of feeding roots is found immediately below the range of cultivator teeth, provided that part of the soil is in good texture. In a warm climate plants root deeper than in a cool climate. Deep cultivation during the growing season cuts off innumerable rootlets and root hairs that are foraging in the richest places they can find. To "plow out" a corn field four or five inches deep, in July, is to practise root pruning of a severe character. Some farm crops do not seem to be injured appreciably by this kind of root pruning, but none are benefited by it, and some are injured. Deep tillage may be given the crop early in the season, if necessary, but shallow tillage after it begins to shoot. Whenever the soil becomes hard, as after a beating rain, a deep cultivation may be needed. Crops that root deeply, as fruit trees, can be tilled more deeply than crops that are shallow-rooted. The aim should be to keep the soil water from getting above that part of the soil in which the roots feed most.

The safest and best general practice, according to present information, is to fit the land deeply and thoroughly before planting, and to cultivate not over three inches deep thereafter, and sometimes less. A loose, dry mulch three inches deep is as valuable a water-saver and weed-preventer as one five inches deep. However, when a soil becomes compact beneath the surface, as clayey soils are very apt to from the tramping above, it is certainly wise to stir it deeply.

THE ADVANTAGE OF LEVEL CULTURE

In earlier years nearly all crops were hilled or ridged when cultivated. Now there is a strong preference for level culture whenever practicable. This preference is based on two facts; that level culture is obviously easier and cheaper; and that less water is lost since it exposes the minimum amount of soil surface to the air for evaporation. How much more surface is exposed when the soil is left like this Λ than when it is left like this —?

Probably the chief reason why the farmers and gardeners of a generation ago hilled their corn, potatoes, and beans, ridged their cotton and planted their onions, carrots, and parsnips in raised beds, more than at present, is because farm soils were not then as well drained as they are now, there being comparatively little under-drainage at that time. There are but two occasions for ridging land:

when the soil is poorly drained, and when the crop needs banking to secure a special result, as celery to blanch the stalks, or potatoes to protect the tubers that crowd out of the ground from being sun-scalded. If potatoes are planted deeply enough, however, all the tubers will form below the surface and hilling is unnecessary.

In the Southern States it is often thought necessary to use two long narrow blades or "sweeps" which cut large weeds just below the surface and ridge the soil somewhat. In the same section a cultivator with one broad blade, quite similar to a plow, is used to throw enough soil over the large weeds at the base of the corn or cotton plants to smother them. This leaves the plants on rather high ridges. It is extremely doubtful if the practice is wise except, perhaps, on the heavier and wetter soils.

If corn, tomatoes, beans, cucumbers, melons, okra, peppers, cotton, and other heat-loving plants are grown upon land that is inclined to be somewhat cold and wet it may pay to hill or ridge them; but there is abundant evidence that on soils that are even fairly well drained this practice is a disadvantage. Very wet soils, especially creek bottom land and meadow muck, are often cultivated in ridges, beds, or hills with excellent results. In all cases the ridges should be no higher than is necessary to accomplish the purpose for which they are made. Not only should hilling and ridging be dispensed with on soils that are rather deficient in moisture, but also the surface should be left as level as possible, by using a shallow-working, narrow-tooth cultivator. In a wet season it may pay to use a deep-working, ridge-forming cultivator, on a soil that is normally so dry that level culture is best for it. Likewise it may be wise to use a ridge-making cultivator in early spring on some soils, to warm and dry them, and replace this with a shallow-working cultivator after the crop is well started and the temperature of the soil is higher.

PREVENTING LOSS OF WATER FROM SOD

How to prevent the loss of soil water in sod land is a more difficult problem, but something can be done. A dressing of manure not only enriches the soil but also acts as a mulch to it, preventing much water from escaping from the bare places between the plants. The gist of the whole philosophy of treating sod land, so as to get full benefit from the water in it, is to have no bare or unshaded places. If the grass plants stand so thickly that all the surface is shaded, most of the water lost from the soil passes off into the air through the plants, much to our profit. But if the meadow is getting worn out, and needs reseeding, a large part of the soil water is lost by evaporation from the bare places between the tufts of grass. Weeds, daisies, dock, thistles and the like may take possession of these bare places that appear in the sod ground when the grass roots begin to get weak; then the loss of water is greater. In handling sod land so as to get the most value from the water in it, endeavour to force most of this water through the grass plants, by keeping the turf dense and clean through occasional plowing and reseeding, and by top-dressing. It is quite possible to have a sod too thick, the result being that many weak grass stalks of poor quality are produced, but turf that is too thick is not nearly as common as turf that is too thin.

CHAPTER VIII

ROLLING, PLANKING, HOEING

FARMERS have long noticed that grain sprouts quickest wherever the horses' hoofs have trod. Gardeners have observed the benefits of walking above newly planted vegetable seeds. They have noticed, also, that the soil on the bottom of the hoof track or foot print is more moist than adjacent soil. The conclusion has been that compacting the surface soil makes it more moist; this view is held by many farmers. Rolling, which had its origin in these observations, is practised by many with the idea that it increases the amount of moisture in the soil.

ROLLING TO ASSIST GERMINATION

The chief object of rolling on many soils is to increase the amount of water supplied to the germinating seeds, but rolling does not actually increase the total amount of water in the soil; it diminishes it. Rolling compacts the surface soil, bringing the particles closer together so that film water passes upward more readily and is lost by evaporation. But while passing upward much of it comes into contact with the seeds and is absorbed by them; thus the seeds are supplied with more moisture and germinate quicker and better, even though it is at the expense of a loss of water to the soil. Since so much of the success of a crop depends upon quick germination, we can afford, on some soils and in some seasons, to sacrifice a good deal of water for the sake of gaining this important result.

The soil at the bottom of the hoof-mark or footprint is more moist than the surrounding soil because it is more compact and losing more water by evaporation, having no mulch above it. The soil in a field that has been rolled is more moist on top than if it had not been rolled, but the soil below the compacted portion, from five to twenty inches deep, is much dryer than it would have been had the surface been left loose. In other words, the upper five or more inches of soil have been made more moist, by rolling, at the expense of the soil beneath. Within twenty-four hours after rolling this difference can be noticed. Part of the loss of moisture from rolled soil is due to the fact that the surface is left very level and smooth, so that it offers less obstruction to the wind. The velocity at which the wind passes over rolled ground may be nearly twice as great as on rough, unrolled ground. This means that much more moisture is sucked from the soil by the wind.

When Rolling to Assist Germination is Practicable.—The farmer must decide whether the gain from rolling, in better germination, is greater than the loss, in the reduction of the total amount of water available for the growth of the crop. That depends upon the rainfall and upon the moisture-holding capacity of the soil. Rolling for the purpose of assisting germination is of greatest value on the lighter, looser and coarse-grained soils, especially the sands and sandy loams. These are so open that the air may circulate through the surface soil quite freely, drying it and stealing water that the seeds need. They are so loose and coarse-grained that the seeds are not sufficiently in contact with the soil to absorb enough water from it. Rolling very light soils is not only an aid to germination, but may also increase their capacity to hold water, providing they are covered with a mulch afterward. It is rarely necessary or practicable to roll clay soils for the purpose of supplying more moisture to assist germination, but they are often rolled to accomplish other results.

Making a Mulch after Rolling.—Most of the rolling now done is on land that has been seeded to grain or grass, and it is done immediately after the seed has been harrowed in. In a majority of cases the surface is left compact, as it comes from the roller, and remains so through the season. This is a waste of water. A way to secure all the benefit of rolling and avoid all the disadvantages is to make a shallow mulch on the surface after rolling. Rolling compacts from five to twenty-four inches of soil; if the upper inch or two are loosened into a mulch, the water drawn up from below as a result is prevented from escaping and most of the seeds get the benefit of it as well. This means that whenever the loss of water by rolling is a detriment, as on light dry soils, the roller should be followed by a very shallow-working harrow, as a spike-tooth harrow with the teeth slanting backward, or a weeder.

In some parts of the country a brush drag is used for this purpose. This is usually made of six or eight small white birch trees, twelve to eighteen feet long. The butt ends of these are fastened into a 2 x 4 inch end piece, at such a distance apart that the trees lie side by side and cover an area of ground about eight to ten feet wide. When dragged over a newly seeded and rolled field the tough twiggy branches stir the surface soil thoroughly to the depth of one to two inches, making a very effective shallow mulch after a heavy rolling. It is better to defer making the mulch for twenty-four hours after rolling, by which time the moisture will have come to the surface.

Other Illustrations of the Principle of Rolling.—The practice of making a mulch after rolling sowed land is not common. Most farmers who roll their seeding leave it so. When rainfall is liberal and the soil is fairly heavy and retentive, so that the saving of water is not a first consideration, this is probably the best plan. But if the summer rainfall is insufficient and the soil quite open, it will usually pay to harrow or brush afterward. On the other hand, the practice of making a mulch after rolling, or otherwise compacting land that is to be put into hoed crops, is necessarily very common. In fitting sandy soils it is well to roll them before the last harrowing.

In garden operations there are numerous and forceful illustrations of the value of establishing a mulch above compacted soil. When I was little more than half as high as a hoe handle, and helped my father plant corn, I used to wonder why he patted down the earth above the kernels and then scattered a hoeful of soil loosely on top of this. The gardener who makes a round melon hill, patted smooth on top and covered with loose soil, and who walks on his row of beets and then covers his tracks; the fruit grower who stamps the earth around the roots of the fruit tree he is planting but leaves it loose on top; the florist who presses his cineraria or petunia seeds into the soil with a board —all are illustrating, on a small scale, the philosophy of rolling.

OTHER BENEFITS OF ROLLING

The chief purpose of rolling, in ordinary farm practice, is to increase the supply of moisture for the seeds, but it may serve other useful purposes, or it may be used for these alone and not for moisture. Rolling to crush lumps is a profitable and common practice on soils which become cloddy. Great care must be taken, however, not to roll these soils when they are wet, as they are then cemented into a hard crust by heavy rolling. There is a time between wetness and dryness when the clods crush easily; this is the time for rolling. The seeds are brought into close contact with the soil by rolling, while they might lie dry and unresponsive among the clods. Rolling heavy soils in spring after seeding is beneficial if the season is dry, but injurious if the season is wet.

The benefits from crushing clods lie not only in the improvement of the soil conditions as affecting germination, but also in the liberation of the plant food that has been locked up in the lumps. Rolling heavy soils, when the chief object is to crush clods, is always attended with more or less uncertainty as regards its influence on the moisture of the soil; so it is usually preferable in such cases to break the lumps with a planker or clod-crusher instead of running the risks of rolling. An incidental benefit of rolling, on some soils, is that it presses all small stones on the surface into the ground, so that they will not interfere with harvesting.

Rolling May Warm the Soil.—Rolling has a marked effect upon the temperature of the soil. It makes it warmer if the weather is clear and warm, but colder if the weather is cloudy and cold. King recorded an average difference of nearly three degrees between the rolled and the unrolled soil of the same field at a depth of three inches, the rolled soil being warmer. The soil becomes colder during cold weather and warmer during warm weather than if it were rolled, since on the unrolled field there is more surface exposed to the air. The more firmly a soil is packed on the surface the better does it conduct heat; so that during the night and during cold rainy weather the rolled land is colder at the surface than the unrolled land.

Incidental Benefits of Rolling.—Incidental benefits of rolling in some cases are that it puts the soil into such a condition that other tools can handle it more effectively; it leaves the surface in better shape for marking; it smooths the soil so that small seeds may be distributed over it more evenly. Fall-sown grass, clover and grain are often rolled in very early spring to lessen the likelihood of injury from heaving by freezing and thawing and to make the surface smoother for mowing. These, however, are insignificant as compared with rolling for moisture and for crushing lumps.

From the foregoing statements it is evident that rolling may be beneficial or detrimental, according to the soil and the season; it is a practice that must be used with discretion. In general, it may be said that rolling accomplishes two very useful purposes; it increases the water-holding capacity of light soils and aids the germination of seeds in them; and it crushes the lumps of cloddy soils. The tendency is to restrict the use of the roller to the first purpose on light soils, where firming the soil is the chief result sought; and to use the planker for the latter purpose on heavy soils, where fining the soil is the end desired. More rolling is done on spring sown grain after the seed is harrowed in than for any other purpose. If the season is dry this gives excellent results; if it is wet and the soil is somewhat clayey the texture of the soil may be injured and a crust formed. If a cloddy clay soil is rolled after having been plowed when it is too wet the clods are likely to be pushed into the ground instead of being pulverised. In rolling, as in plowing, everything depends upon "catching the soil at the right time."

THE KINDS OF ROLLERS

When the main reason for rolling is to compact the soil, the roller should be as heavy as is expedient. The larger it is in diameter the heavier it should be. It is well to have a roller of large diameter for it pulls easier in proportion to its weight. For ordinary purposes a roller should weigh at least 1,500 lbs. Wooden rollers, which are usually made in one, two or three sections, are cheap and quite effective, although many of them are light. Their rolling surface soon becomes rough, thus increasing the draft. Iron or steel rollers, which are usually in more than two sections, last longer, do better work and pull easier. The more sections a roller has the less it furrows the ground in turning around. Some iron rollers are made with teeth or with corrugated surfaces or blades; these are claimed to be more effective in breaking lumps, but they often clog badly, thus increasing the draft and decreasing the effectiveness.

PLANKING

Closely allied to the roller in its effect upon the soil is the tool variously known as a planker, clod-crusher, smoother and sometimes as a drag, boat float or plank harrow. The terms "drag," "float," and "boat," however, are more properly applied to the tool known as a "stone boat" in the East, which is about 2 x 5 feet, smooth on the bottom, not corrugated, and which is used, not for mellowing the soil but for hauling stones from the field, plows and harrows to the field and similar work. The planker is usually home-made and therefore is not uniform in construction. A few cultivators have planker or clod-crushing attachments.

Nearly all home-made plankers are made of two hardwood planks about 2 x 8 inches and 6 to 8 feet long. Notches about two inches deep and eight inches apart are made in each of these bed pieces and into these are nailed or bolted 2-inch planks about six feet long, each plank overlapping the one next to it, like clapboards. Or several planks may be merely overlapped and bolted together. Some prefer to have a space of several inches between the planks. This is pulled broadside and exerts a powerful pulverising and smoothing influence on the surface, especially if weighted with a driver or stone ballast.

The planker has very little compacting effect, as compared with the roller, because its much lighter weight is distributed over many square feet of surface; while all the weight of the roller rests upon the narrow line where its curved surface touches the soil. The planker is distinctly a clod-crushing and levelling implement. In this respect it resembles the harrows and is very properly called a plank harrow. The planker is now used where the roller was formerly—to crush the lumps on heavy loams and clay soils that do not need compacting. On tenacious soils it is a common practice to use the disk harrow after plowing, followed by the planker, the Acme or spike-tooth harrow and then the planker again, alternating harrowing and planking the soil until it is brought into the right condition. The last turn should be with the planker, as it leaves the surface mellow and smooth, so that fine seeds may be sown or the land marked out for planting.

The planker breaks up many of the small lumps that slip through harrow teeth and presses others into the ground where they can be torn out and broken to pieces by the subsequent harrowing. The planker is one of the most useful tools that any farmer can have, especially if the soil is somewhat heavy. It is never used to compact the soil around the seeds, as a roller, but is always used like a harrow—as a pulveriser and leveller after plowing. It is superior for this purpose to the roller; it should be used in place of the roller in all cases but two; upon light soils which need compacting and upon seeding.

HOEING

In primitive agriculture the plow and the hoe were about the only tillage tools used. Of late years the hoe has been used less and less as an implement of tillage. It has been forced aside by the increasing necessity for doing as much of the work on the farm as possible with horse power. The harrow, the cultivator and the weeder now do much of the work that was formerly done with the hoe and do it much better. It is noticeable that where hand labour is cheap, as in parts of the South, a much larger proportion of the farm tillage is done with the hoe than where labour is dear, as it is in most parts of the North and West. A negro and a hoe is one of the typical scenes of the South. It is likely that the hoe will become of still less importance in farming, as we learn better ways of circumventing the weeds before they are big and as we are forced to perfect other means of growing crops with as little hand labour as possible.

Aside from its use as an aid to planting, which is constantly lessened by the increasing use of planting machines, the hoe will always be useful for two purposes; to kill large weeds that have escaped the cultivator and to stir the soil close to the plants where the cultivator teeth cannot work without danger of injuring the plants. The hoe is a very poor tool for making a mulch; it stirs the ground deeply in some places, lightly in others and usually parts of the surface are left wholly undisturbed, or are raised slightly by the passing of the blade beneath them. It does not lift, crumble and invert the soil, as do cultivator teeth, unless the soil is very mellow and dry. As an implement for conserving moisture, therefore, the hoe should be used only where a cultivator cannot be used; that is, close to the plants.

Hoeing to Kill Weeds.—For killing large weeds the hoe has no equal, but this is an expensive way of killing them. Most of them can be killed when very small by frequent shallow cultivation. There are various styles of cultivator teeth and attachments to cultivators that are designed to skim below the surface and cut off large weeds. These wings, sweeps and other special weed-killing devices should be a part of every farm equipment; if used in time they should reduce the area that needs hoeing to the parts adjacent to the rows. Here is where the hoe must be used, especially if it is found desirable to ridge the rows. With some crops the weeds that start between the plants can be killed when very small by using the spike-tooth harrow or weeder over the entire surface. But after the plants are too large for this it is a struggle to keep down the weeds in the rows. They get a start close to the plants and gradually encroach upon the cultivated area. It is then time to "cut out" the rows; and it is likely the workman will have to pull some of them by hand, so closely are their roots and stems entwined with the crop.

Good and Poor Hoeing.—The easiest and most rapid way to hoe is to barely skim the ground with the blade at a very slight angle to the surface, scarcely disturbing the soil, but cutting off the weeds. The hardest and slowest way to hoe is to strike the blade into the ground at a sharp angle, lifting and turning two or three inches of soil. The former is preferable on the lighter and looser soils, the latter on the heavier soils and especially when the ground about the plants has become compacted by rains or tramping. Some men use the hoe as they would a pick; it does little good in this way so far as conserving moisture is concerned. As a general rule, hoeing, like cultivating, should be deeper in spring than in summer, and for the same reasons.

It is as much an art to hoe well as to cultivate well, and sometimes just as much depends upon it. Not one man in ten gets as much out of a hoe as there is in it. It is not enough to hoe merely to kill weeds, it should also save soil water and secure all the other benefits of tillage. This means that the soil should be stirred around the plants to a nearly uniform depth, not merely stabbed deeply in places and a thin layer of loose soil scattered over the unstirred soil between. It also means that the surface should be left nearly level, not in hog-troughs. Many farmers who are careful enough with their cultivating are slovenly with their hoeing. Market gardeners, however, have learned that it pays to put as thorough a man at work with the hoe as with the cultivator,

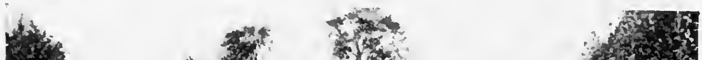
Styles of Blades.—The blade of the hoe used in general farming does not vary much in size and shape. The essential thing is to keep it sharp and bright, which it will not be if hung up in the apple tree all winter. The business hoe makes frequent visits to the grindstone. As a general rule the blade on a new hoe is too broad to work handily; when it gets worn down an inch or two, it cuts the soil easier and better. Hoe blades having rounded teeth on the cutting edge are preferred by some. Some gardeners have many hoes of different sizes and shapes, some of them with blades only an inch wide for picking out weeds between vegetables; or with the handle inserted between two blades of different widths. Others are shaped like a narrow triangle; or heart-shape, with the lower end notched; or with the blade reduced to the merest hook, so that a stray weed can be tweaked from the ground with a twist of the wrist. The handles of some of these aristocratic hoes are knobbed on the end and variously curved. This is too gingerly work for most of us. The old-style hoe blade, about three and one-half inches by six inches,

62. ROLLING WHEAT SEEDING IN A DRY SEPTEMBER

This compacts the soil around and beneath the seeds so that they receive more moisture and germinate better. It may pay to follow the roller with a brush or "drag" to make a shallow mulch

63. A CLODDY SOIL THAT WOULD BE BENEFITED BY ROLLING

If the lumps are crushed, the soil fits tighter around the seeds, and there is more feeding surface for the roots



64. A FOUR-SECTION IRON ROLLER WEIGHTED

The more sections a roller has the less it cuts into the ground in turning answers every purpose when used with timeliness and thoroughness.

MISCELLANEOUS HAND TOOLS

There is an almost endless variety of hand tillage tools designed to be used when the rows are too close together to admit of horse tillage or for working close to the plants. These are of far greater relative importance in gardening, especially in market gardening, than in general farming, because gardening is usually conducted under more intensive culture than general farming. Wheel hoes, hand cultivators, scuffle hoes, hand weeders and the like are indispensable in commercial or home gardens, but rarely needful on farms where staple crops are grown, because these must be grown with as little hand-labour as possible in order to make them pay. Moreover, the hand tools can be used to best advantage only on soil that is exceedingly mellow and free from stones—a condition that many farms cannot meet. In short, they are tools for intensive culture; hence they are of greater value to the gardener, who is forced to locate very near his market on valuable land, and who must adopt intensive culture in order to make the business pay, than for the farmer who grows staple crops, and who can locate further from the market on cheaper land where such intensive methods are not needed.

It is noticeable that even in gardening operations the tendency is more and more to dispense with hand tools. Crops that were formerly planted in rows twelve or fifteen inches apart, so that tillage had to be done by hand, are now frequently planted in rows twenty-eight or thirty inches apart so that the cultivator may run between them. Some horses have a mathematical eye and will keep their feet between rows two feet apart without leading; and the spike-tooth cultivator can be narrowed to work between these rows, thus saving much wheel hoeing and hand hoeing. It is harder and much slower work to push a wheel or scuffle hoe than to follow a cultivator. There are conditions, however, when close planting may be desirable, as in the home garden or in market gardens close to towns, or for certain crops that thrive best when the plants partially shade each other, as onions and root crops.

Hand Cultivators.—Nearly all hand-tillage tools beside hoes may be classified as hand cultivators, scuffle hoes or scarifiers, and hand weeders. Hand cultivators, erroneously called wheel-hoes, are of a great variety of patterns, but all attempt to do the work of a cultivator on a small scale. The larger the wheel and the wider the tire the easier it overrides obstacles. Those with two wheels are steadier, and also useful for straddling the row and cultivating on both sides. Several styles of interchangeable teeth are usually sent with each tool, including spike teeth, coulter teeth, hillers or ridging sweeps and a large furrowing shovel. A hand cultivator does excellent work in mellow soil; it is one of the most serviceable of gardening tools. Many prefer it to the scuffle hoe for tilling onions, carrots, radishes, lettuce and other closely planted crops.

Scuffle Hoes.—These are of service chiefly between rows planted less than fifteen inches apart, as onions, carrots and the like. They are made in various styles, but all have a single blade which is pushed with a jerky motion along the ground, cutting from one-half inch to one inch below the surface. The blade varies from half an inch to four inches in diameter and is rectangular, crescent or looped. The style most commonly used is attached to a long straight handle. A better style for some purposes is attached behind a wheel, thus becoming in reality a wheel hoe. The handle style is better after the tops of the plants begin to lean toward the middle of the row.

The scuffle hoe, like the common hoe, is a poor tool for making a mulch, but a most excellent tool for killing weeds. It barely skims the ground, cutting off weeds just below the surface and running very close to the row; but the soil is not inverted or loosened much. Very often it is simply sliced. An excellent plan for tilling close planted crops is to alternate the hand cultivator and the scuffle hoe. They complement one another; the former makes a mulch, but some of the larger weeds may slip through its teeth; the latter cuts off the weeds, but is a poor mulch-making tool.

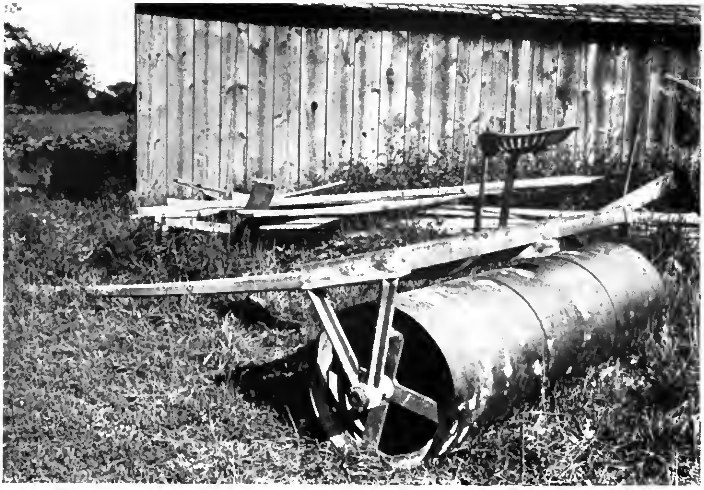
In addition to these larger hand tools there are many kinds of hand weeders for even finer work. Some are patterned after the original hand weeder, —the outspread fingers. Others are scuffle hoes with a small blade and short handle. Where it is necessary to do much hand weeding close to the plants, and it sometimes is in market gardening, these little tillage tools will save the fingers and facilitate the work.

SELECTING FARM TOOLS

Before leaving the subject of tillage tools, a word about the selection and care of farm tools in general may not be amiss. The first cost of farm tools is high and they lose from 5 to 25 per cent. of their valuation every year, even with the best of care. They are a very expensive part of the farm equipment, more expensive in proportion to their utility than almost any other item in farm management. It is business policy to get along with just as few tools as possible. Many American farmers have too many. Some men seem to have a sort of mania for collecting everything new or unique in the way of tools. They lie around beneath the apple trees, back of the woodshed and beneath the eaves of the overcrowded tool shed, rapidly falling into disuse, then into rustiness and finally into rottenness. It is an expensive pastime.

Every tool that is not used represents just so much capital, not tied up, but wasted. I know a farmer who has over twenty-five kinds of plows and harrows, yet he uses but six or seven in the work of his farm and finds these sufficient. He has at least $600 tied up in tools that he rarely uses and could get along without just as well. This is not business. The first cost of the few tools that are absolutely necessary is large enough and their depreciation rapid enough, without adding the weight of tools that are not needed. It is all right to try new tools if it can be afforded, but most people had better stick to the few tools that they have found necessary for satisfactory results.

A Variety of Tools Needed.—These remarks about the common and needless waste on American farms because of a superfluity of tools are not meant to deny that a considerable variety of tools are needed on most farms. A good farmer, like a good mechanic, has a tool for every purpose, the best one to accomplish a certain specific result in handling the soil or crop, not one that is fairly



65. A THREE-SECTION IRON ROLLER

Iron rollers are more efficient and more lasting than wooden rollers and do not clog as much. They should weigh not less than 1,000 lbs.

66. A HOME-MADE, THREE-SECTION WOODEN ROLLER

Note the device for keeping it clean. Wooden rollers quickly wear out

67. A SERVICEABLE HOME-MADE PLANKER, OR "FLOAT"

The distinctive use of the planker is to crush clods in soils that it is not best to compact with a roller. The roller sometimes pushes hard clods down into the soil; the planker usually pulverises them good for several purposes. He is not satisfied to use a spike-tooth harrow after the plow when a heavy disk harrow is needed to chop up the sod. He does not like to get along with a walking plow, however excellent work it may do, if a sulky plow will do the work as well, and easier and cheaper. To get each part of the farm work done in the best possible manner and at the least cost is the point that should decide the question of what kind of tools and how many. Five might do the work after a fashion; but if ten would do it enough better, quicker, easier and cheaper to more than pay for the cost of the other five it is economy and profit to have them. One-plow-one-harrow-one-cultivator farmers are the kind that say "farming don't pay."

Just how many tools it will pay to buy is, therefore, a problem for each farmer to decide. He should not stint himself on those that are really necessary; a few bushels more corn per acre, the result of fitting the land better with a good tool, will pay for it in a single season. He should be careful not to indulge himself in tool getting, without sufficient justification for the outlay, however pleasurable that is to the man who loves to handle soil. First of all he will need to consider the kind of soil to be handled. Certain tools do better work on heavy soils than on light soils; if the farm has several types of soils, as is most likely in northern United States, it may pay to keep tools for each. The crops to be grown will also determine to a large extent the types and number of tools needed. Finally the size of the farm or the area of the crop will determine whether it will pay to buy a certain useful tool to do a certain amount of work. This must be the deciding point. Often it would be extremely useful to have a certain tool, but the amount of work that it would be called upon to do is so small that it would not pay for itself.

Tools represent so much capital and have such a vital relation to the productivity and economical management of the farm that the problem of what kinds to get and how many deserves more attention from farmers than is usually given it.

CHAPTER IX

DRAINAGE OF FARM SOILS

NO OTHER farm practice has added to the value of agricultural lands in the eastern part of the United States more than under-drainage. Excess of water in the soil is as fatal to most farm crops as deficiency. A soil must be able to rid itself of surplus water before it can be cropped and it often happens that this is the only defect of many soils that are otherwise very valuable for farming. Fortunately it is usually quite practicable to remedy this defect by drainage.

A Problem of the Eastern States.—Drainage is, for the most part, a problem of the states east of the Mississippi. Probably it would pay to under-drain from 20 to 30 per cent. of the farm land in this region. On the prairie lands of the central West under-drainage is practised more than in any other part of the country, and it has added immeasurably to the wealth of that section. West of the Missouri and Mississippi in general, and in the regions of scanty rainfall in particular, the drainage of lands is often necessary, especially on alkali soils, and is frequently used; but it is insignificant when compared with the need of drainage in the humid regions of the East. What irrigation is to the West, drainage is to the East, although both are needed more or less each side of the great rivers. Until quite recently drainage has received the most attention in this country; now irrigation has come to the fore and claims, and receives, its due. A large share of the unprecedented progress in American agriculture during the past twenty-five years is due to the more general use of these two coördinate farm practices, each of which has the same general purpose in view—to give the crop an adequate and equable supply of moisture.

The surplus water in a soil, which it is purposed to remove by drainage, all comes from rainfall; but rarely is it only that which falls upon the soil itself. The water may flow upon it as surface drainage from higher land, or it may come from below, being rain that has fallen upon higher land, sunk into the soil, followed a ledge of rock or layer of impervious soil, and finally found its way to the surface of the lower land as a spring, oozing from a hillside or bubbling up from the subsoil. Quite often level land which is not surrounded by higher land, and which contains only the water that falls upon it, is benefited by drainage because the soil is shallow. In such cases the most beneficial result of drainage may be, not to remove excess water, but to increase the amount of moisture that the soil can hold—a seeming paradox that is explained farther on.

WHEN DRAINAGE IS NEEDED

Two kinds of soils need draining; those that have too much water, and those that are too shallow. The signs of poor drainage are obvious. Swamps, marshes, meadows and all other low land on which water stands for any considerable time may be drained, provided there is fall enough to secure an outlet. These low lands may be those which collect surface drainage, or seepage from nearby higher land: or they may be lands that are regularly flooded by fresh water or by tides. Farm land which dries out slowly in spring, making the working and growing season shorter, or on which water stands for a long time after heavy rains, needs to be drained. If water oozes into the plow furrow the soil is too wet for good farming.

The kind of plants that take possession of a field, before it is broken up or after it has been laid down in sod, or after it has been neglected for a year or more, are usually a reliable index to its need of drainage. If bog and water-loving plants become established here and there, especially sedges, rushes and mosses, the soil is too wet. Certain spots in the field, usually the lowest places, will indicate their need of drainage in this way, although most of the field is all right.

All of these surface indications, however, should be supplemented or verified by an examination of the water table. Dig a hole in the field from four to six feet deep. If water stands in this hole within three feet of the surface or less, during most of the growing season, it is quite certain that the roots of cultivated plants do not find enough room, air and warmth in that soil to produce the largest crops. The growth of the crops themselves supplies evidence. On poorly drained soils the plants start slowly, look sickly and stunted, and never make the profitable growth of neighbouring plants on well-drained soil. Both yield and quality are reduced. Within the boundaries of one field there are often both well-drained and poorly drained places. The contrast in the growth of plants under these two conditions is usually sufficiently marked to impress the farmer with the need and profit of draining the land.

Under-draining to Deepen Shallow Soils.—There is another class of soils—those that are shallow—that are improved by being drained, but these are not too wet except for short periods. First, there are the soils that have a hardpan close to the surface, perhaps within one to three feet. This hardpan may be a stratum of rock, but more often it is a layer of stiff and impervious clay. The rock hardpan cannot be improved, but the clay hardpan can. Water cannot readily penetrate it. It is like the bottom of a shallow pan; when a heavy rain comes, the pan soon fills and overflows, making surface water. This can escape by surface drainage or by evaporation. But such a soil quickly dries out and suffers in a drought, because it has so little depth. What is needed is to deepen the soil—to lower the bottom of the pan—so that it will hold more water.

There are two important ways of deepening a shallow soil. If the hardpan is close to the surface, stirring the surface with a subsoil plow helps, since it loosens the soil deeper than the plow, thus enabling it to hold more water. But the loosened soil becomes compacted again in a few years; at best the results of subsoiling are only temporary. Under-drainage is permanent subsoiling; it takes away the water that has cemented the subsoil, and permits the air to enter it, thus promoting all the fining, loosening and mellowing influences of weathering. The value of under-drainage for deepening a soil is witnessed on thousands of Eastern farms.

Draining to Improve Texture.—Still another type of soils—those poor in texture—is often greatly benefited by being drained. These are mostly the clayey soils that get hard, lumpy, and unmanageable when dry, and sticky when wet. They are not what would be called wet soils, neither are they shallow, but they are not mellow and they run to extremes, either very dry or very wet. It is impossible to work them early in spring. Heavy rains put them in such a condition that they cannot be cultivated for several days after the crops begin to need tilling. The surface bakes and cracks. Such soils are improved by plowing under a green-manuring crop, by under-drainage, or by both. In many cases the addition of humus is sufficient to bring the soil into good heart; in extreme cases under-drainage must be called to the aid of humus.

Land drainage is not chiefly concerned, as many suppose, with carrying off surplus water from very wet soils. Drainage adds far more to the value of farm soils, and to the profits in cropping them, by improving soils that are shallow, or in bad texture, or but slightly wet, than by removing excess water from very wet soils. Many thousands of acres of swamps, meadows and marshes have been brought under profitable husbandry by drainage; but the combined area of these is very small compared with the hundreds of thousands of acres of farm lands that are not excessively wet, but that have been greatly improved by the same means. Drainage, and especially under-drainage, is of greatest service upon land already under cultivation, but which is not yielding maximum crops because of inequalities in the water supply. Farmers should make a critical examination of each field in this respect, regardless of the length of time that it has been cultivated. Deficiencies may exist that never have been suspected.

LAND WITH GOOD NATURAL DRAINAGE

The foregoing remarks should not obscure the fact that in some cases it may be more practicable to buy land that has good natural drainage than to drain wet land. All farm soils need draining; but fortunately most soils are well-drained naturally. There is a great area of American farm soils that have almost perfect natural drainage, and a still greater area of soils that are drained quite satisfactorily. These are mostly sandy or loamy soils, or soils rich in humus; and especially soils that have an open subsoil which is sandy, or gravelly or of about the same nature as the surface soil. Water passes through some of these soils so readily that they can be worked a few hours after a heavy rain. The bulb fields near Puget Sound, Washington, have a soil so open that men can work in it within an hour after a rainfall of over one inch; yet it is very retentive and moist at all times. The causes of this very equable condition are the large amount of humus that the surface soil contains, and the subsoil of fine, sandy loam.

One of the first points to look after when buying farm land, then, is its drainage, for Nature can drain land much cheaper than man. Dig several holes, five or six feet deep, to see what kind of subsoil lies beneath the surface that looks so promising. The value of a soil for cropping depends almost as much upon the former as upon the latter. The "lay of the land" is also important. Sloping land is not necessarily well-drained land. A slope may provide good drainage, and it may not. It carries off much excess water as surface drainage, to be sure, but we wish the soil drained for at least four feet below the surface. Some of the most poorly drained farm soils are on slopes. They are usually clayey and may have springs oozing from them. In other words, a slope is an aid to good drainage, but the nature of the soil and its elevation with reference to surrounding land are far more important factors.

WHEN IT WILL PAY TO DRAIN LAND

Not all land that would be greatly benefited by being drained will it pay to drain. It is a question of economics as well as of securing maximum productiveness. It might be more practicable, for example, to put a certain field of hard and rather wet soil into grass, which usually grows fairly well under these conditions, or at least better than most other farm crops, than to go to the expense of draining it for corn, cotton or rye. The more exacting the crop, as regards an equable supply of moisture, the more likely is it that it will pay to drain the land. Likewise the higher the value of land, and the more intense the culture, the greater are the arguments for drainage.

Again, it might pay to drain land used for special crops which have a high value per acre, as market-garden crops, when it would not pay to drain this land if it were planted to staple crops, which have a lower value per acre. Furthermore, it might not pay to drain a certain field if the farmer has plenty of other land which is better drained, and land is cheap. Much also depends upon the kind of soil, and the difference between its present value and its value after being drained. The same system of drainage may add $10 per acre to the value of a poor soil, and $100 per acre to the value of rich soil.

These, and other points in farm economics, should decide the practicability of draining land, after the need for draining it has been clearly proved. There is much farm land now producing indifferent crops, and the owners do not even suspect that its mediocrity is due to poor drainage. The first cost of draining land is large and the returns from the outlay are not immediate; they are distributed over many years. It may be several years before the drains have paid for themselves. This fact is responsible for much of the hesitancy among farmers about undertaking an improvement that they readily admit is needed. They hate to "bury their money," or to put into the soil and out of sight an improvement the operation of which they cannot watch. The same argument, however, might be raised against the use of a fertiliser; the operation of neither can be watched, but the effects of both are readily seen. There is a deepening interest in farm drainage as land increases in value and as it becomes correspondingly necessary to make plants comfortable, so that they may be grown at the lowest possible cost of production.

EFFECT OF DRAINING ON THE SOIL

The direct benefits of draining land have already been pointed out in the chapters on the nature of the soil and on soil water. The most important result is that it makes the soil warmer. A wet soil is cold, chiefly because the water in it is constantly evaporating, and evaporation is a cooling process. To illustrate this: If the bulb of one thermometer is covered with wet muslin, and the bulb of another similar thermometer is left uncovered, the wet thermometer may register as much as 15 degrees cooler when both are swung in dry air. This is due to the cooling effect of the evaporation of the water. Moreover, water is a poor conductor of heat; wet soils warm in the sun slowly, because the water they contain holds down the temperature. There is usually a difference of 5 to 10 degrees between drained and undrained soil in the same field. In fact, the temperature of a soil in summer is very largely determined by the amount of water it contains; the wetter it is the colder it is. Warmth is one of the chief essentials for the germination and growth of farm crops; it is the coldness of a poorly drained soil, more than the mere excess of water it contains, that is responsible for most of the unsatisfactory growth of crops upon it.

Draining a soil allows the air to enter it more freely. If all the spaces between the soil grains are filled with water air cannot enter. Air is one of the most important agencies that help to make a soil productive. It changes the rock particles of the soil into plant food and is essential to the decay of plants in the soil, making humus. Seeds must have air or they will not germinate. The soil bacteria that make fertility cannot thrive without air; the more thoroughly and the more deeply a soil can be aërated the richer it should be, and the better should plants grow upon it. The depth to which air penetrates the soil increases when the water-table is lowered by drainage, hence a larger feeding area is presented to the roots.

Draining a Soil Makes it More Moist.—Although it may seem a paradox, draining a soil may make it more moist at the times when moisture is needed most. This is a feature of drainage that many people find hard to understand, yet the explanation is very simple. Drainage lowers the water-table, thus increasing the volume of soil above it in which the roots of plants can feed, for they can use only film water. The larger the area of soil above the water-table, the more film water there is for the plants to use. They root deeper and so are farther away from the dry surface soil. Furthermore, a soil is more mellow after being drained than before, so it can absorb and hold more water as film moisture, and its ability to draw up water from the water-table is increased. Under-drainage simply carries off free or standing water, thus leaving more room for the film water that plants use. Hence it is that a drained soil is dryer in a wet time and more moist in a dry time than before it was drained.

In humid regions under-drainage may be equivalent to irrigation as a means of supplying water to the crop. The farmer who drains his land owns more soil than he did before; for until the water-table was lowered he had the use only of the soil above it, the only part in which the roots of his plants can feed. If he lowers the water-table two feet he adds a layer of soil two feet thick to his property. He has two feet more of soil in which the roots of his plants may find nourishment. This is the cheapest way of increasing the size of the farm.

After a soil has been drained the roots of plants penetrate it deeper, earthworms burrow deeper in it, air follows these channels and the ventilation of the soil is still further improved. A system of tile drainage is itself very effective in aërating the

68. CORN "DROWNED OUT"

The aggregate loss of crops by poor drainage is enormous. Much of this loss can be prevented

69. MEADOW ON WHICH WATER HAS BEEN STANDING

The land now has no value for cropping. It could be drained at a slight expense

70. A SOIL WELL DRAINED NATURALLY BY A GRAVELLY SUBSOIL
Examine the subsoil when purchasing land

71. SURFACE DRAINAGE BY "PLOWING INTO LANDS"
The dead furrows in this meadow are 10 paces apart. They lead the water into a shallow ditch on the side of the field

soil. Most of the time the tiles carry air, as well as water. When the surface air is much warmer than the soil air, as on a warm day in early spring, a system of tile drains may supply a slight bottom heat, or at least be the means of equalising temperature. Thus a good system of under-drainage aërates the soil both from above and from below.

Practical Results from Draining Land.—The practical result of the better aëration and increased warmth secured by draining land is that the soil becomes richer and more productive. Not only does more plant food in the soil itself become available, but also the manures or fertilisers that may be applied are more effective, since they too must first be treated with Nature's chemicals before the plants can use them. The beneficial bacteria of the soil, which thrive only in warmth and moisture—not wetness—are encouraged to multiply. The season is lengthened at both ends; the soil can be worked earlier and later, so crops have the use of it longer.

If a poorly drained field is sloping there may be a considerable loss of fertility by surface washing. After this field is drained, rains sink into the soil more readily, as it is looser and dryer, and so a large part of the surface washing is checked. The cost of growing a crop is reduced, especially in preparing the seed bed, for a mellow, well-drained soil is easier to handle and can be brought into the right shape quicker than cloddy, poorly drained soil. Seeds germinate better, because the soil is warm and dry instead of cold and wet.

The quality as well as the yield of the crop is often improved. This is particularly true of grass or hay; that which grows in well-drained meadows or pastures is of much higher value for feeding than that which grows in wet land, not only because the better grasses thrive in the well-drained soil, but also because they actually contain more nutriment. These and other benefits of draining wet, shallow or hard soils may be crystallised into one sentence; draining increases the producing capacity of such soils and enables the man who tills them to put his crops upon the market at a lower cost of production.

WHAT KIND OF DRAINS TO USE

Soils are drained in two ways, by surface drains or by under-drains. Which method should be followed is mainly a matter of expediency and of thoroughness. Surface drainage is secured chiefly by means of open ditches. The objections to open ditches as compared with under-drains are numerous and forceful. They cost more than tile drains, both to make and to maintain. More soil must be moved for surface drains than for under-drains in order to make the ditch of the needed capacity and to give the banks sufficient slope so that they will not wash. Ditches need frequent repairing and cleaning out, the sides cave in, they become choked with plants, many of which may be noxious weeds, and the soil washes in.

Ditches take up much valuable space and hinder the use of teams. In order to thoroughly drain a wet field the ditches would need to be so close and so large that they would occupy one-fifth to one-sixth of the area. This is too much to lose if under-drains will do just as well. Furthermore, the loss of water from open ditches by evaporation is very great. It amounts to from 40 to 50 inches of water a year, in the Eastern States, and much more than that in the arid regions.

These objections are sufficiently forceful to make drainage by open ditches entirely impracticable when tile drains can be used. There are many sections of the country, notably in the South, where it is dangerous to provide any kind of surface drainage, because the soil washes so badly. All kinds of surface drains everywhere carry away more fertility than would be lost through under-drains. In most cases it is better that excess water should pass through a soil instead of over it.

WHEN DITCHES ARE PRACTICABLE

There are, however, conditions under which surface drainage is not only useful, but is about the only kind of drainage that is at all practicable. In peaty or muck bogs, fresh and salt water marshes, cranberry bogs and the like, the open ditch is the only feasible method of drainage, at least for the larger drains. In these cases the main object is to carry off the flood or surface water; the water-table is not lowered to the depth that is necessary for most farm crops. Whenever it is wished to lower the water-table of such lands to four feet and to plant them with the common farm crops, it is usually necessary to supplement ditching with tile drainage.

Tile drains cannot be laid in marshes in which the peat is not well rotted until they have been partially drained by open ditches. When a peat soil is drained it shrinks; if tile drains had been laid the tile would soon be found too near the surface. In such cases it is preferable to first put in open ditches to dry out the marsh until the shrinkage has occurred. Get a crop started upon the marsh as soon as possible, as it hastens decay. Later these ditches may be deepened and tile drains laid in the bottoms of them.

According to King, another occasion when open ditches are feasible is in draining very level land underlaid by a very fine clay. These places are usually found where a lake once existed. Water moves through the fine clay so slowly that tile drains would not be effective unless laid so close that the expense would be prohibitive. Such soils should be plowed into lands from twenty to thirty feet wide with the dead-furrows emptying into shallow ditches.

Ditches are also useful to provide an outlet for under-drains, and to catch surface drainage on slopes, or at the foot of slopes. In other words, ditching is useful mainly for taking care of surface water, and for removing the excess of water in the first foot or two of soil. Deep and thorough drainage, such as most farm crops demand, can usually be best secured by under-drainage.

HOW TO DIG A DRAINAGE DITCH

The depth, width and grade of a ditch depends chiefly upon the amount of water to be removed, the lay of the land and the nature of the soil. In marsh lands the ditch may usually be cut to a depth of four or six feet, and with almost vertical sides. Peat or muck soil is not liable to wash or cave in, being more or less fibrous, especially if the water-table is not lowered sufficiently to dry out the soil so deep that it will shrink and crumble the banks. Ditches in an upland soil, however,

72. DRAINING WET LAND WITH AN OPEN DITCH

Ditching is much inferior to tile draining, where the latter is expedient, being more expensive in the long run and not as lasting. But only ditches are practicable on some marsh land. The sides of this ditch are too steep

73. AN OPEN DITCH WITH GRASSED SIDES ON AN EASY SLOPE, SO THEY DO NOT WASH

All ditches take up much room. They become foul with weeds and must be cleaned out

74. LAYING A TILE DRAIN

The ditch is four feet deep. The line of tiles is given a fall of one to four inches in 100 feet. The joints are fitted together carefully

75. A TILE THAT HAS BEEN CLOGGED BY TREE ROOTS

The whole drain may be obstructed in this way. Lay sewer pipe when the drain passes near trees, and cement the joints must have sloping banks. If the soil is a tenacious clay a slope of 15° to 20° may be sufficient to hold the banks. More often a slope of 45° is barely enough to prevent caving in, which means much extra work. The greater the fall of the ditch, the flatter should be the banks.

In many cases, especially for wet meadows, the best kind of ditch is merely a broad hollow, about one or two feet deep and six or eight feet wide. These places may be grassed over, if in a meadow; if the land is used for tilled crops and the ditch serves as a water carrier only in winter and early spring, it may be planted. All kinds of farm machines can pass over such a ditch; it is the most serviceable kind whenever it will drain the land sufficiently. On nearly all comparatively flat land, and especially on western prairie land, there are many shallow natural water-courses, variously called "runs," "draws" and "sloughs." The heavy spring rains turn these into drainage channels. If necessary shallow ditches, ten or twelve feet wide and two feet deep, may be scooped out in these draws with plow and scraper and the bottom and sides seeded to grass.

The Grade.—The grade of an open ditch must be low. A fall of five or six inches in a hundred feet is usually about all that an ordinary soil will stand without washing, especially if the banks have not enough slope. If it is necessary to make curves in a ditch, they should be very gradual, particularly if the fall is greater than it ought to be, for when the ditch runs full the water will tend to eat into the outer bank, as it does in streams. When an average ditch is running full after a freshet a fall of two inches in a hundred feet makes a current of about four miles an hour. This current quickly undermines steep banks unless the soil is very fibrous or clayey. It is usually best to grass over open ditches; some sort of herbage will soon cover the banks anyhow, but grass roots are more valuable as soil binders.

The distance apart of open ditches is governed entirely by the nature of the land. In marsh land the small laterals, which may be about three feet deep and three feet wide on the bottom, are frequently placed from 40 to 100 feet apart, and empty into larger main ditches, which are five or six feet deep and equally wide on the bottom. In some cases it is better to dig larger ditches from 150 to 200 feet apart.

PLOWING INTO LANDS

This simple and very common device for surface drainage has already been mentioned in Chapter V. It is useful solely for removing the excess of free water, especially that which stands upon the surface. Plowing a field into lands makes very shallow open ditches. It is quite common to leave dead-furrows about fifteen or twenty feet apart, thus throwing the soil into slightly raised beds or lands. The dead-furrows should usually lead to open ditches on the side of the field. This dries out the soil and warms it earlier in spring.

If the soil is liable to remain wet late into the spring, and especially if it is a heavy clay, the dead-furrows may be in the same place for several years, thus deepening the hollows and elevating the lands. On average soils, however, the dead-furrows should be made in different places each year. According to Roberts, lands five or six paces wide do not drain off the surface water of nearly level fields as effectively as lands twenty to twenty-five paces wide, "because not enough water is carried into any one of the dead-furrows to produce a current sufficient to overcome the obstruction offered by clods and friction." Surface drainage by dead-furrows is most practicable on very fine clay soils, through which water passes so slowly that it would be almost useless to lay tile drains beneath them. Sometimes the dead-furrows may be joined by cross furrows, so as to convey the water away along a natural depression.

THE ACTION OF UNDER-DRAINS

In most cases under-drains are more efficient and more practicable than surface drains. Under-drains may be of stone, boards, brush, or other materials, but tile drains made of baked clay are now used almost universally. Drain tiles have come into common use within fifty years. There are now many thousands of tile factories at work in the United States. Any clay that will make good bricks is suitable for making tiles. Few parts of the country where tiles are most needed, especially east of the Mississippi, are without facilities for making drain tiles.

The philosophy of under-drainage is simple. An open passage is made through the soil below the water-table; that is, below the point at which water fills all the spaces between the soil particles. It is like boring a hole into a water tank two feet below the point where the water stands in the tank, and inserting therein a pipe. The water is lowered to the level of the bottom of the pipe. Lines of 3-inch tiles are run through the subterranean lake; they lower its surface to the level of the bottom of the tile at the points where each line of tile runs. But the level of the water-table rises higher between the lines of tile, as water cannot move as freely through the soil as it does in the open. Thus the surface of the water-table of a tile-drained field is something like a series of crescents, the lines of tiles being at the lowest points.

The height to which the water-table rises between the lines of the tiles depends upon the distance apart of the drains and the character of the soil. The farther apart they are, the higher the water rises between them. The more sandy or porous the soil, the more nearly does the water-table come to the level of the drains over all the field. Thus, if under-drains are placed four feet deep in a sandy soil, and a similar distance in a clayey soil, the water-table of the former might be lowered to an average level for the field of three and one-half feet and the latter to two and one-half feet.

It must be clearly understood that under-drains carry off only free water, never film water. Furthermore, they remove no water from a soil unless the water-table is above them. Water does not run into them, it is squeezed in. For instance, if a line of tile drains is placed four feet deep in a soil in which the water-table is four feet six inches below the surface in summer, none of this water will get into the tiles until the water-table has been raised to four feet, or over, as it might be early in spring after heavy rains.

Water enters tile drains through the joints and also through the walls of the tiles. It is not necessary, as many suppose, to leave a crevice between the tiles for the entrance of water. No matter how tight a joint is made, water will pass in freely. In laying tile, therefore, the object should be to make as tight a joint as possible, so that dirt will not enter and clog the tiles.

PLANNING THE DRAINAGE SYSTEM

The attempt to drain a piece of land, no matter how small, should be preceded by careful planning. The direction of the drains, the distance between them and the grade should be plotted on paper. The aim should be to lay out the system so as to secure sufficient fall and give adequate drainage with the least digging and the least amount of tile. To this end it is necessary to make few outlets and junctions and not to lay two lines of tiles so close together that they both drain an area that could be drained by one line.

On small areas having a noticeable fall, the drains may be located by eye and the planning may be done without the aid of a surveyor; but much land that requires draining is quite flat and it is extremely difficult to give the drains the right grade without the assistance of an instrument. It does not pay to go to the expense of buying tile and digging ditches only to make a botch of the job by trying to save the cost of the services of a competent drainage engineer. Nine times out of ten the work of laying out the drainage system on a large area should be entrusted to a surveyor.

The owner of the field should, however, contribute his knowledge of local conditions. He should know, for instance, the source of the water it is expected the drain will remove—whether it comes from overflow, springs or otherwise—so that the drains may be laid to cut off the supply with the least amount of digging. He should know the wet spots in the field and if the outlet of the drainage system is to be on the bank of a stream, he should know the high-water mark of the stream. Only the man who tills the field and observes the condition of the soil at all times of the year can locate a drainage system upon it most economically.

It may be cheaper and better to have a large job done entirely by a drainage engineer. He has a force of men who are familiar with all the ins and outs of the business, and can dig a ditch, lay tile and finish the work much quicker than men who are unused to the business. It is especially important that the man who lays the tile should be skilled, or if not skilled at least very careful. Cheap help for this work is poor economy.

In planning a system of under-drainage the various points should be considered in the following order: First, select the best outlet. Second, locate the position of the main or mains. Third, ascertain the difference of level between the outlet and the highest point in the main, and determine the grade. Fourth, locate each of the laterals. Fifth, find the difference in level between the highest point in each lateral and the point where it joins the main, and determine the fall. Under all circumstances work from the outlet or outlets back to the furthermost laterals.

Make an exact plan of the system on paper, drawn to a scale. A man usually thinks he can remember just where the drains are located, but in a surprisingly short time all traces of them on the surface are obliterated and recourse must be had to a map. Failure to make a map may cause much inconvenience and useless digging when the drains need attention later.

THE OUTLET

The first point to look after is the outlet; the water must be carried off after it is collected by the tiles. More than one drainage system has given poor service solely because a suitable outlet was not provided. The channel into which the drainage system discharges may be a natural water course, as a river, creek, brook, or rill, or it may be an open ditch constructed for the purpose. If a natural water course, it is very essential that the outlet of the drain be at least several feet above the highest point at which the water in the stream has been known to stand. This precaution is necessary to prevent the stream water from backing up and filling the lower end of the drainage system, which not only prevents the drainage water from escaping, but also allows the stagnant water to deposit sediment on the bottom of the tiles and choke them. All the water in a tile drainage system should be in motion all the time.

The outlet is the most vulnerable part of a drainage system; it is the only part that comes to the surface. Hence it will pay to deepen and straighten the course of the stream at that point, if necessary, in order to make it doubly sure that the drainage water will meet no obstruction in passing from the outlet. For the same reason it is usually best to have as few outlets as possible; to collect the water from many or several lines or systems of drains into one main with a single outlet. Sometimes, however, it is cheaper to have several outlets, one for each system, instead of uniting all into one main. The cases are rare when it is best to let each line of tile have an independent outlet.

The outlet should be kept clear of weeds and soil, guarded from the tramping of animals and protected from injury by frost. In the Northern States it is not safe to run the ordinary soft tile to the surface. The last ten feet, at least, should be of more durable material, as a box drain made of 2-inch plank; or, better yet, the last ten feet may be of glazed sewer tile. Cast iron sewer tiles are sometimes used. It is well to face the bank at the outlet with brick or stone. There should be a wire screen over the outlet to prevent the entrance of small animals. Examine the outlet at least twice a year to see that it is free.

THE GRADE OF TILE DRAINS

The amount of fall or grade that under-drains should have depends upon the contour of the land, the length of the drains and the character of the soil. The first thing to do is to locate the outlet above all possible danger from obstruction by back-water. The height above the outlet of the highest point of land that is to be drained must next be determined. For example, there may be a difference of seven feet between the outlet and the upper end of the main, and the distance is 1,200 feet. This means that the main may have a fall of five inches per hundred feet, which is about right. The main drain must follow the lowest land from the outlet to the head of the drainage system, and be given as much fall as possible, within a reasonable limit, so that the lateral drains will have sufficient fall. The fields that are most likely to need draining are apt to be rather flat and there may be considerable difficulty in deciding off-hand where the lowest land is, and along what line between the outlet and the upper part of the field the greatest fall may be secured. In doubtful cases a level should settle the question.

Having established the outlet and located the main drain on the lowest land, next locate the laterals, or collecting drains. The fall of the entire system must now be considered. In general it should be from 5 to 8 inches in 100 feet. If this grade can be secured there should be no difficulty in laying a system that will work perfectly. But very often 2 or 3 inches in 100 feet, or even less, is as much fall as can be had. Excellent drainage systems are now in operation that have a fall of 2 inches in 100 feet, and there are occasional examples of farm drainage systems that work with a fall of even ½-inch in 100 feet. But these can be constructed only with the aid of a skilled engineer. In farm drainage a fall of at least three inches should be sought; if one must content himself with less grade he should employ a surveyor and give greater attention to the laying of the tiles.

On the other hand, too much fall in a drainage system is equally undesirable. A fall of 12 inches in 100 feet is considered about the limit of safety. A greater grade would carry the water so fast that there would be danger of loosening the tiles. This is especially true on lighter soils, which frequently have tile drains washed from them after a very heavy rain. If any of the tiles are loosened sufficiently to admit soil the whole system may be ruined eventually.

If possible it is best to have all the drains laid at a uniform grade, from the upper end of the system to the outlet. If it is necessary to change the grade it should preferably be from a less fall to a greater, say from 3 inches to 4 inches in 100 feet; if the grade is reduced there is greater likelihood that the sediment in the water will settle in the lower part of the system. To avoid this, if a reduction in grade is necessary, put a "silt basin" at the point where the change is made. This is made by sinking an 8-inch, 10-inch, or 12-inch tile below the level of the ditch, and notching it on one side for the drainage water to flow in, with a lower notch on the opposite side for the first tile of the new grade. The soil dropped in here should be cleaned out occasionally. Carry the silt basin to the surface with glazed sewer tile; or, if the line of tiles is large, dig a larger basin and brick up the sides. Silt basins should be covered all the time with iron, stone, or plank to avoid accidents and freezing. Silt basins are really small wells; they enable the farmer to see if his drains are working properly, as well as collect silt. They may be placed at the junction of the sub-mains and the mains, even if there is no change in grade, so as to give an opportunity to examine the working of the drains.

DEVICES FOR ESTABLISHING GRADE

The most important part of under-drainage is the grade. If the grade is insufficient the water stagnates and the tiles become filled with soil. If any part of the system, even a few feet of it, is below grade the whole system suffers. Hence the necessity of securing the services of a skilled drainage engineer if a large area is to be drained. The use of a surveyor's level is not indispensable to good draining, but is extremely helpful. If a small area is to be drained, and the land is not very flat satisfactory work may be done by a careful man without a level.

A Home-made Level.—There are many simple devices for establishing a grade. King recommends a "water level," which is easily made at home. It is made of a piece of $\frac{3}{4}$-inch gas pipe, four feet long, with a T exactly in the center and an elbow at each end. A piece of pipe about six feet long is inserted in the T and sharpened at the lower end, making the standard which is thrust into the ground. A short piece of glass tube, $\frac{1}{2}$-inch in diameter, is cemented into each L and the top of each tube is fitted with a cork. Each tube should project exactly the same distance above the L. Fill the gas pipe with water, coloured with ink or bluing, until it just shows in both of the glass tubes when the pipe is exactly horizontal. When using this improvised level, stick the standard firmly into the ground, remove the corks and adjust it until the water shows that the horizontal pipe is perfectly level. Then step off four or five feet and sight across the top of the two tubes. If used carefully, this instrument does quite accurate work for short distances.

There are many ways of using this and other kinds of levels. The simplest way, for drainage work that is not complicated, is to first set the level some 50 or more feet from the outlet. Sight back to the outlet, set the measuring rod on the ground and note the height at which the level sight strikes the rod. It may be 4 feet 6 inches, for example. With the instrument in the same position find the height at which the sight strikes a rod, set about 50 feet in the opposite direction, along the line which it is supposed the drain will run; say at 5 feet. The difference between the back-sight and the fore-sight is thus six inches, showing that the land has a fall of 6 inches in 100 feet, or in the distance between the two points at which the rod stood. The instrument may now be moved forward and similar measurements taken for the remainder of the main and for the laterals. The fall that the entire system can have is thus determined.

The next thing to do is to stake out the drains. Beginning at the outlet drive into the ground a stout peg 8 or 10 inches long until it is flush with the surface. Drive similar pegs 50 feet apart along the line where the ditch will come and about 12 inches to one side of the centre of the ditch. About a foot from these "grade pegs" drive "finders," stakes which project a foot above the ground and guide one to the grade pegs.

The work of determining the grade and depth of the ditch may now be begun, using the level as indicated above and taking the height of the top of each grade peg by placing the rod upon it. Thus, if it has been determined that the drain may have a fall of 4 inches in 100 feet, at which grade it will be 3 feet 6 inches deep at the outlet, if the next grade peg is four inches higher than that at the outlet it shows that the bottom of the ditch at that point should be 3 feet and 8 inches below the level of the grade peg. Measurements are taken all along the line in the same way and the depth which the ditch should be at each fifty-foot point is recorded in a book, and on each of the finder stakes. When laying the tile a cord is stretched along the tops of the grade stakes and the depth for laying is determined with the aid of a measuring rod, which has an arm at a right angle and long enough to reach to the line.

A Sighting Method.—Brooks recommends a simpler and scarcely less accurate device for securing the right grade. Drive two stakes at the outlet, one on each side of the position of the ditch, so that when firm their tops are a little over six feet above the level of the drain at the outlet. Thus if the outlet must be 3 feet 8 inches deep the tops of the stakes will be a little over 2 feet 4 inches above the level of the ground. Nail a light, narrow board from stake to stake so that the top of it will be level and exactly six feet above the bottom of the drain. Go to the upper end of the drain and place a similar grade board just 6 feet above the bottom of the ditch there; if the drain is 300 feet long, and a grade of 3 inches in 100 feet can be secured, this grade board will be nailed 9 inches above the surface.

At intervals of 50 feet on the line of the drain set similar pairs of stakes. The height at which to nail the grade boards on these is determined by sighting from the lower to the upper grade boards, or vice versa. Dig the ditch nearly to the desired depth. Now stretch a stout cord very tightly from the top of the grade board at the outlet to the top of the grade board at the upper end of the drain, and midway between the stakes, where the centre of the drain should be. Brace the upper and lower grade boards to prevent the line from sagging. When the ditch is completed the bottom at all points should be exactly six feet below the cord.

The success of this device depends upon the accuracy with which the sighting is done and the grade boards nailed, upon a taut cord, and careful measuring to the cord. The latter operation is done with a rod and great care should be taken to hold it exactly vertical. A spirit level will aid in this. See that the cord does not stretch during changes in the weather. When carefully executed this simple method of grading gives very satisfactory results.

There are many other home-made devices for establishing grades, as the walking level, and those in which a spirit level is used. When the field has a noticeable slope a careful workman can make a fairly accurate grade by simply watching the flow of water in the ditch. But it is not best to depend upon the eye alone, except, perhaps, for very small fields which have a pronounced slope.

THE NUMBER AND DIRECTION OF DRAINS

This is determined by the contour of the land and the character of the soil. If a more or less continuous depression runs through the field, somewhere near the middle, the drains would probably have but one outlet, with one main following the depression, and with laterals running obliquely from it to the surrounding higher land, unless something could be gained by a short cut. If there were two depressions there might be two mains, which would unite to make one outlet. If the whole field slopes slightly in one direction, say toward an open ditch, the water in which never rises above the point at which the outlet of the drains would be, mains might be dispensed with altogether and the field drained by parallel lines of small tile running from the upper end of the field to the ditch, each having an independent outlet.

The mains should make sweeping curves, not abrupt ones. The laterals also may join the mains at any angle, depending entirely upon the grade. If the main is in a marked depression it may be necessary to run the laterals nearly parallel with it for some distance, so as not to make their fall too great, making a long acute angle; but if the main is in a very slight depression the laterals may be almost or quite at right angles to it. In any case they should be given a slight curve before they join the main, so that the water may be carried into the main with the current, not across it.

When draining land that has a marked slope the lines of the tile may be run up and down the slope, across it, or obliquely. If there are springs on the slope these will be cut off most effectively by cross-slope drainage. otherwise it makes little difference which method is chosen except for the difference in fall. Most drainage engineers prefer to run the drain obliquely down the slope whenever it is expedient.

There are thus many systems of laying out tile drains, each of which has merits under certain conditions. The contour of the land, the character of the soil and the position of the outlet usually decide this question. In fact, it is often necessary to put in a combination of several systems on one field, because of the variation in contour. In planning any system of tile drains the aim should be to use 3-inch tiles in preference to larger sizes, wherever they can do the work, for the larger size of tiles add greatly to the expense of the system. Every field is a new problem; no one can tell how the drains ought to run without studying the field.

DISTANCE BETWEEN UNDER-DRAINS

This depends chiefly upon the nature of the subsoil and the depth of the drains. The ease with which water can pass through the subsoil to the drains would naturally have much influence in determining the distance apart of the laterals. Water will pass to the drains through a sandy subsoil from ten to one hundred times more rapidly than through a stiff clay subsoil. The coarser the subsoil and the freer it is from hard-pan the more readily does water move to the drains and the farther apart they may be placed. In other words, the more open the subsoil is the farther apart should the drains be, for the excess water in such soils quickly drains off. The movement of water in compact subsoils is very slow.

The depth of drains should be considered in deciding their distance apart; the deeper they are the lower do they make the water-table. Under-drains do not lower the water-table of the entire field to their own level. At the point where the drains are placed it is lowered to that level, but midway between two lines of drains it may be several inches or even several feet higher, depending upon the openness of the soil and the ease with which water passes through it laterally. The water-table of an undrained field is a series of curves or crescents, the lower ends of each curve being on a level with the bottom of the drains. So the deeper drains are placed the farther apart they may be without danger of the water-table coming too near the surface, midway between the lines of drains.

The common distances apart for laying tile drains are 20 to 30 feet on deep, very compact clays;

40 to 70 feet on average loams with a rather open subsoil, and 100 and even 200 feet on very open soils. A safe distance for average loam soils in the Eastern and Central States is 40 to 50 feet, if the depth is not less than $3\frac{1}{2}$ feet; and 25 to 40 feet on heavy clay soils. Many fields may be excellently drained with some lines of tile 40 feet and some 100 feet apart, according to the nature of the soil in different parts.

DEPTH OF UNDER-DRAINS

The deeper the drains are placed, within reasonable limits, the better they work. But beyond a certain depth the expense of moving soil increases faster than the advantage gained in the way of better drainage. In certain soils it may cost about twice as much to dig a ditch four feet deep as it does one three feet deep. For ordinary farm crops the depth to which the ground water should be lowered need not be over four feet, and frequently less. If the land is too wet only in the early part of the season, and it is desired merely to lower the water-table sufficiently to dry out the land quickly in early spring, drains placed two and one-half or three feet deep will usually answer the purpose.

It may happen that the only available outlet is so high that it is necessary to place the drains at less depth than what is considered best, so as to secure sufficient fall for the entire system. Again, if the field has a sandy or gravelly subsoil some four or five feet below the surface, it would be unwise to place the drains so deep that the water-table would be lowered into the sand or gravel, because this coarse soil has poor capillary power and the soil above it would be but poorly supplied with film water after the water-table is lowered into it. In the Northern States it is absolutely necessary to lay tiles below the frost line anyway, for they are easily heaved and cracked by frost. This means a depth of two to three feet, and even four feet in the northern prairie states. In the Red River Valley of Minnesota and the Dakotas the ground freezes six feet deep, and there is much doubt as to whether tile drains are practicable there. It is not practicable to try to place drains so deep that the roots of ordinary crops will not enter them, for these roots commonly run from five to ten feet deep.

The best depth for drains on average soils is three and one-half to four feet. There are few cases where lateral drains should be five feet, or over, but mains are frequently laid at that depth. It is rarely expedient to lay deep drains in stiff soils; shallow drains are much better, for water moves slowly through heavy soils. Land that is to be permanently in grass may have the drains laid more shallow, not only because the grass will prevent the ground from freezing so deep, but also because grass thrives when the water-table is nearer the surface than is best for most tilled crops. Under-drains in such lands are often laid two and one-half to three feet deep with excellent results, especially if the soil is not very heavy. Thirty inches is about the minimum depth, under any circumstances, at which it is practicable to lay drains. When laying drains in peaty land make allowance for the settling and shrinking of the soil from the decay of the vegetable matter.

KINDS OF TILES

At least eight styles of tile have been used since the beginning of tile drainage, but at the present time practically all farm under-drainage is done with round tiles. Sole and double-sole tiles, which are flat on one, two, or four sides, are heavier and can be joined together only in two ways; whereas a round tile can be joined to its neighbour at any point. Six or eight-sided tiles with a round bore are quite popular in the West and have all the merits of round tiles, except that collars cannot be used with them, which is unnecessary in most cases. However, they have no advantage over ordinary round tile and it is doubtful if they can be laid as rapidly.

There are a number of special forms of tiles for certain uses. "Elbows" or L's are made in all sizes, either with a slight curve or a curve of 45 degrees. They are used principally for the mains. At the point where a lateral empties into the main, or a sub-main into the main, "junction pieces," or branch tiles, are necessary. These may be Y's or T's, the Y's usually being preferred. The use of a Y is almost indispensable at junctions, in order to prevent an accumulation of soil and displacement of the tiles at that point. "Collars" are tile rings two or three inches long, which are slipped over the outside of the tiles to cover the joint. They prevent soil from washing in and hold the tiles in place; but they cost so much and the incovenience of applying them is so great that they are impracticable except where there is great danger of tiles being displaced, as where the fall is sharp and the soil rather light. "Enlarging tiles," which taper, are useful at the point where the drain changes from one size to a larger size, as from a 3-inch to a 4-inch, making the joint much more perfect than if the 3-inch tile were butted against the larger one.

When buying tiles it is important to stipulate that all be perfect. Some lots of tiles contain many that are not fit to be used in a drainage system; one poor tile may undo the work of many good ones. Good drainage tiles do not crumble and when struck on iron have a ringing, metallic sound, not a dull, wooden sound, showing that they have been well burnt. Tiles that are badly warped or chipped at the ends are worse than useless. They should be smooth inside and cut square on the ends. Glazed tiles are more durable than unglazed, but there is little difference in efficiency.

SIZE OF TILES

A system of tile drainage should have sufficient capacity to carry off the excess water of the heaviest rains that fall, inside of twenty-four to forty-eight hours. The time when under-drains are most taxed is in early spring when the soil is already saturated. The greater the fall of the system the smaller the tiles may be, because water is carried off more rapidly. Formerly 1- and 1½-inch tiles were quite commonly used for lateral drains; now 2-inch tiles are the smallest used, for it costs but little more to make them than the smaller sizes. They are easier to lay to grade and safer. Two-inch tiles are still used in the Eastern States, but not so much as formerly, being largely replaced by the 3-inch size.

The sizes of mains and sub-mains are capable of fairly accurate calculations, as their capacity varies with the square of their diameters.

Wheeler makes the following estimate of the relative capacity of different sizes of tiles:

A $2\frac{1}{2}$-in.	tile	will	carry	$1\frac{1}{2}$	times	as	much	water	as	a	2-in.	tile
" 3	"	"	"	$2\frac{1}{2}$	"	"	"	"	"	"	"	"
" 4	"	"	"	5	"	"	"	"	"	"	"	"
" 5	"	"	"	$5\frac{1}{2}$	"	"	"	"	"	"	"	"
" 6	"	"	"	$12\frac{1}{2}$	"	"	"	"	"	"	"	"
An 8	"	"	"	25	"	"	"	"	"	"	"	"

Chamberlain gives these rules for estimating the size of mains: When the fall is not more than 3 inches in 100 feet the diameter of the tiles should be squared and the result divided by 4. Thus a 3-inch main will drain $2\frac{1}{4}$ acres; a 4-inch main, 4 acres; a 5-inch main, $6\frac{1}{4}$ acres; and so on. When the fall is greater than 3 inches, square the diameter and divide by 3. In this case a 3-inch main will drain 3 acres; a 4-inch main, $5\frac{1}{3}$ acres; a 5-inch main, $8\frac{1}{3}$ acres; a 6-inch main, 12 acres, etc. These rules have been found to be quite reliable on ordinary soils.

On heavy soils the different sizes will drain more than the area given, as water moves through them more slowly. Elliott says, "For drains not more than 500 feet long a 2-inch tile will drain 2 acres. Lines more than 500 feet long should not be laid of 2-inch tiles. A 3-inch tile will drain 5 acres and should not be of greater length than 1,000 feet. A 4-inch tile will drain 12 acres; a 5-inch tile, 20; a 6-inch, 40; and a 7-inch tile, 60 acres." The capacity of tiles is thus seen to vary widely in the judgment of experts. The size of the main increases as it proceeds toward the outlet and receives the drainage of the larger area.

DIGGING THE DITCH

The largest expense of establishing a system of under-drainage is in moving the soil. Many steam and horse-power machines have been invented for doing this work, but most of it is still done by hand. Most of the machines require more power than can ordinarily be furnished conveniently; but some, that are designed merely to loosen the surface, are very serviceable. If a large area is to be drained it will be economy to hire men who have had experience in the business, when they can be had.

In order that no more soil may be moved than is absolutely necessary, it is customary to stretch a stout line 4 or 5 inches back from where one side of the ditch should be and cut true to the line. The width of the ditch on the surface need not exceed 20 inches, even for large mains, and 12 or 15 inches is ample for lateral drains. Beginners always dig ditches wider than is necessary. The ditches should taper downward evenly, being but 4 or 5 inches wide on the bottom, if 3-inch tiles are to be laid. In case the drains are laid more than 4 feet deep it may be necessary to make them a few inches wider.

The surface soil may be partly moved with a plow if it is not very heavy or very stony. After the line is stretched a very deep furrow is turned with an ordinary plow, which may then be followed by a trenching plow, or another furrow may be turned with a landside plow. Part of the soil is thus moved out, and part is so loosened that it is handled easier. The trench is then finished with a spade. Many, however, prefer to open the entire ditch with a spade. An ordinary spade answers the purpose for a small job, but a ditching spade, which has a narrow, curved blade about 18 inches long, is preferable.

The soil should be placed on the edge of the ditch, not thrown away from it. Both surface and subsoil are placed upon the same side of the ditch, and usually it is not necessary to keep them separate. In some cases it may be cheaper to have the ditch dug by contract, except grading the bottom to receive the tiles, which should be done by an experienced and careful hand. If quicksand is encountered the sides of the ditch will need to be supported with boards, braced by sticks between them. Besides the spade, a tile hoe is a convenient but not indispensable tool. It is used for cleaning out and grading the bottom of the ditch. It comes in various sizes, according to the size of the tiles laid, and makes a half-round groove into which the tiles fit snugly.

Ditching should be begun at the outlet and the main should be laid back to the first lateral. This junction is then made and two or three tiles of the lateral are laid before the main is laid further.

LAYING TILES

It is well to begin laying the tiles as soon as a strip of ditch is graded, for if a storm arises enough water may run into the bottom of the ditch to spoil the grade. Usually it is best to begin laying the tiles at the lower end of the system. They are first placed in a line along the edge of the ditch. The man who lays the tiles may stand in the ditch or he may stand on the edge of it and handle the tiles with tile hooks, with which they may be turned and twisted until the joints are satisfactory. Professional tile layers often do very rapid and satisfactory work without getting into the ditch; inexperienced men had better lay the tiles by hand.

The joints should be as close as possible; here is the place for extreme care. There is no danger that water will not enter the tiles freely enough, even with the closest joints, but there is always danger that soil will wash into the tiles. All tiles have a slight curve; turn them in the bottom of the ditch until they fit against each other snugly. If junction or branch tiles are not used at the junction of the laterals with the main, the former may be let into the latter through a hole cut into the main with a small pick or short, pointed hammer; but the two should be joined very neatly and the joint packed with clay. A better way is to pick a hole in the top of the main, another near the end of the last tile of the lateral, and place the two openings together after plugging the end of the lateral with a stone and clay. Some drainage experts think it pays to put cloth, paper, sod, and other coarse materials over the joints before filling in the soil: others find this is not necessary.

FILLING THE DITCH

In filling the ditch be especially careful not to displace the tiles and to get the soil packed tightly about them, so that there may be no chance for a water channel outside the tiles. Usually it is best to cover the tiles four to eight inches deep as fast as they are laid, using the soil last thrown out, if it is clay. This is done by a man in the ditch following the man who lays the tiles, while a third man on the bank shovels in soil, being careful not to throw in large stones. This is tramped around and over the tiles, care being taken not to move them out of line.

The remainder of the ditch is filled very rapidly in any way that is handiest. An ordinary scoop scraper may be used if the team is hitched to it by a long chain and works on the opposite side of the ditch. Sometimes the ditch may be filled most economically entirely by hand. A wooden scraper shaped like a snow plow drawn backward is sometimes serviceable for filling a ditch when the soil is mellow. A road scraper is very serviceable for finishing the filling after the ditch is nearly closed. It is well to tramp the soil several times in the process of filling. Leave the soil around the ditch rounded, for it will settle. It is not absolutely necessary to fill in the subsoil first and the surface soil last, but this should be done as far as is convenient.

OBSTRUCTIONS IN TILE DRAINS

If the grade is too flat to carry off the water before the sediment in it settles, or if any tiles are displaced, the drains may soon become partially filled with soil. This is especially likely to occur when the subsoil is clay. The time of greatest danger is the first two years; after that the soil becomes compacted about the joints. It is sometimes necessary to dig up poorly laid tile drains every three or four years and clean out the mud in them. When the fall is sharp and uniform, and the joints well made, there ought not to be any trouble from this source.

The filling of tiles by the roots of trees is another possible cause of trouble. These often enter the joints and fill the interior of the tiles with a dense wad of small roots, completely closing the bore. Willows, elms, white maples and other water-loving trees are the worst offenders. If possible, avoid laying drains within thirty to sixty feet of trees, according to the size of the trees. If a line of tiles must run close to a tree use sewer pipe near it and cement the joints. This is the great difficulty in tile-draining orchard land. The roots of other farm crops rarely clog a tile drain. The obstruction of drains by animals, as frogs, muskrats and rats, is prevented by covering the outlet with wire netting or iron grating.

When a drain is clogged the land near the obstruction gradually becomes wet, and but little water flows from the outlet. A partial obstruction may sometimes be removed by flushing, which is done by closing the outlet of the drain until the drain and the surrounding soil are filled with water, then opening it. The comparative level at which water stands in small deep holes dug parallel to the suspected drain will usually locate the exact point of an obstruction.

COST OF LAYING TILE DRAINS

→ This is from $12.00 to $60.00 per acre according to the number of ditches opened, the nature of the soil and the cost of tiles and labor. The more the larger sizes of tiles are used the greater is the expense. The expense of digging the ditch and laying the tiles should average about $3.00 to $4.00 per 100 feet for laterals, and more proportionately for the mains. The cost of tiles varies greatly; the list prices of the manufacturers are usually

76. THE PLOW MAY BE USED TO FACILITATE THE REMOVAL OF SURFACE SOIL FOR DRAINS

Usually, however, the work is done entirely with a ditching spade

77. OUTLET OF A TILE DRAIN CLOGGED BY SOIL SO THAT THE DRAIN DOES NOT WORK

It should be kept free of all obstructions, and is preferably bricked up. A wire screen keeps out small animals that might obstruct the drain

78. A TYPICAL EASTERN SWAMP THAT CAN EASILY BE MADE INTO FARMING LAND

subject to large discounts. On an average they will cost:

2-inch	tile	$1.00	per	100	feet
2½ "	"	1.30	"	"	"
3 "	"	1.50	"	"	"
4 "	"	2.25	"	"	"
5 "	"	3.75	"	"	"
6 "	"	4.50	"	"	"
7 "	"	6.80	"	"	"
8 "	"	9.00	"	"	"

The cost of tiles for mains is thus two or more times as much as for laterals; hence the necessity for making the main as direct and short as possible. The expense of filling the ditch may be estimated at from thirty to forty cents per hundred feet. Professional drainage engineers usually figure on a total cost of from $15.00 to $25.00 per acre when a large field under average conditions is to be drained. If an inexperienced man does the work it is likely to cost much more than this.

OTHER KINDS OF UNDER-DRAINS

Before tile drains were perfected, various other materials were used, chief of which were stones, plank and brush. Very rarely are any of these drains practicable now; tile drains are usually cheaper and always more serviceable. When flat stones are abundant a stone drain may be feasible, but it costs as much to put in a good stone drain as a tile drain. The large, flat stones are laid so as to form a continuous channel. If there are many stones on the surface these can be thrown in above the drain. Stone drains are very likely to clog with soil, as the joints are so poor.

Box drains are made of three or four 2-inch planks, with short pieces of laths between the larger joints to provide an opening for the water to enter the drain. They are cheaper than stone drains, but quickly decay. On newly cleared land, brush and pole drains are occasionally used, especially if chestnut or cedar wood is abundant. The brush is piled in the bottom of a ditch and covered with soil. Pole drains are made by laying three small logs so as to form a channel. Both are crude and temporary at best, giving poor or fair service for only a few years. "Mole drains," made by drawing a conical piece of wood through the soil by steam power at a depth of two or three feet, have been known to do fairly good work for several years in clay soils, but they cost nearly half as much as tile drainage and are not permanent. All these kinds of drains are most successful on clay soils. After having gone to the expense of digging a ditch it is far more practicable in most cases to put in tile drains, which are durable and efficient, instead of these uncertain substitutes.

DRAINING POT HOLES

A problem which many farmers would like to have solved is how to drain low places which are surrounded on all sides by land so high that it is entirely inexpedient to cut through it for an outlet. In many cases it will cost more to drain such places than they will be worth afterwards, but sometimes it will be worth while to try one of the following methods: If the land is made wet almost entirely by surface drainage, it may pay to dig a ditch around it to intercept the surface water. If it is found that there is a bed of sand or gravel within ten or fifteen feet of the surface, as is sometimes the case, it may be practicable to sink a well through the surface soil that holds the water, which is usually clay or silt, into the more open subsoil below. This well may be filled with stones to within three or four feet of the surface, and the balance with sand or soil; or it may be stoned up and used as an outlet for tile drains. If expedient, this water may be pumped out by a windmill and used for irrigating surrounding fields. Water-loving trees, as willow, larch and white maple, will do much to drain these places in summer when in full leaf, but unfortunately they are of no help in early spring when such lands are most likely to be wet.

DRAINING LARGE SWAMPS AND MARSHES

Aside from its value for improving farm soils already under cultivation, and for bringing into service meadows and small swamps, examples of soil drainage on a large scale are becoming more and more numerous. Shaler estimates that there are over 100,000 square miles of swamp land in the Eastern Atlantic Coast States alone which can be reclaimed and made into profitable farming land by drainage. It is estimated by one authority that there are 600,000,000 acres of swamp land in the United States. Some of these lands, which include salt marshes and large fresh-water swamps and meadows, are already being reclaimed. When drained they usually become exceedingly productive, partly because they contain so much humus, and partly because they are perfectly sub-watered at all times of the year. The great area of land wrested from the sea during half a century by thrifty Holland, equalling the combined areas of Rhode Island and Delaware, is an illustration of what much of our salt marsh land may become when diked and ditched. It is certain that during the next half century immense drainage projects for the reclamation of large swamp and marsh areas in the East will be no less numerous than the irrigation projects for the reclamation of the arid lands of the West. The United States Department of Agriculture has an Office of Irrigation and Drainage Investigations, employing many experts, which has assisted in the draining of over 300,000 acres of land during the past three years.

CHAPTER X

FARM IRRIGATION

IT is estimated that there are now about 250,000 square miles of irrigated land in the world. This great area is receiving very large additions every year. The principal countries where irrigation is now practised are India, the United States, Egypt, Italy, Spain, Germany, France, England, Scotland, in about the order named. Irrigation is also followed to a lesser extent in Belgium, Japan, Switzerland, Denmark, Austria-Hungary, Argentina, Australia and many other countries. India has 25,000,000 acres under ditch, Egypt 6,000,000, Italy 3,700,000. Some of the irrigation canals now used in India date from the twelfth century. The British government is expending several hundred millions of dollars in developing the Indian irrigation systems, besides which there are not less than 400,000 private wells used for irrigation, serving 2,000,000 acres. In Italy the government controls all the streams in order that they may be available for irrigation. King states that irrigation canals are so numerous in Egypt that not one-tenth of the water of the Nile reaches the Mediterranean.

In this country irrigation is confined chiefly to the arid and semi-arid (also called sub-humid) sections. In 1902 the number of acres under ditch was as follows:

AREAS IRRIGATED IN THE UNITED STATES, 1902

From Census Bulletin No. 16.

Arid States

State	*Area, Acres*
Arizona	247,250
California	1,708,720
Colorado	1,754,761
Idaho	713,595
Montana	1,140,694
Nevada	570,001
New Mexico	254,945
Oregon	439,981
Utah	713,621
Washington	154,962
Wyoming	773,111
Total	8,471,641 acres

Semi-arid States

State	*Area, Acres*
Kansas	28,922
Nebraska	245,910
North Dakota	10,384
Oklahoma	3,328
South Dakota	53,137
Texas*	61,768
Total	403,449 acres

Rice States

State	*Area, Acres*
Georgia	8,581
Louisiana	387,580
North Carolina	3,422
South Carolina	38,220
Texas	168,396
Total	606,199 acres

*Exclusive of rice irrigation.

Humid States

State	*Area, Acres*
Alabama	95
Connecticut	379
Florida	3,772
Maine	17
Massachusetts	283
Mississippi	114
New Jersey	48
New York	159
Pennsylvania	906
Rhode Island	15
Total	5,788 acres
Grand Total	9,487,077 acres

Under date of Oct. 23, 1906, Mr. Elwood Meade, Chief of Irrigation and Drainage Investigations, United States Department of Agriculture, writes: "I think these figures might be increased by 10 per cent. to represent the present area. The increase is very generally distributed, so that you would not be far wrong to increase the area for each state 10 per cent."

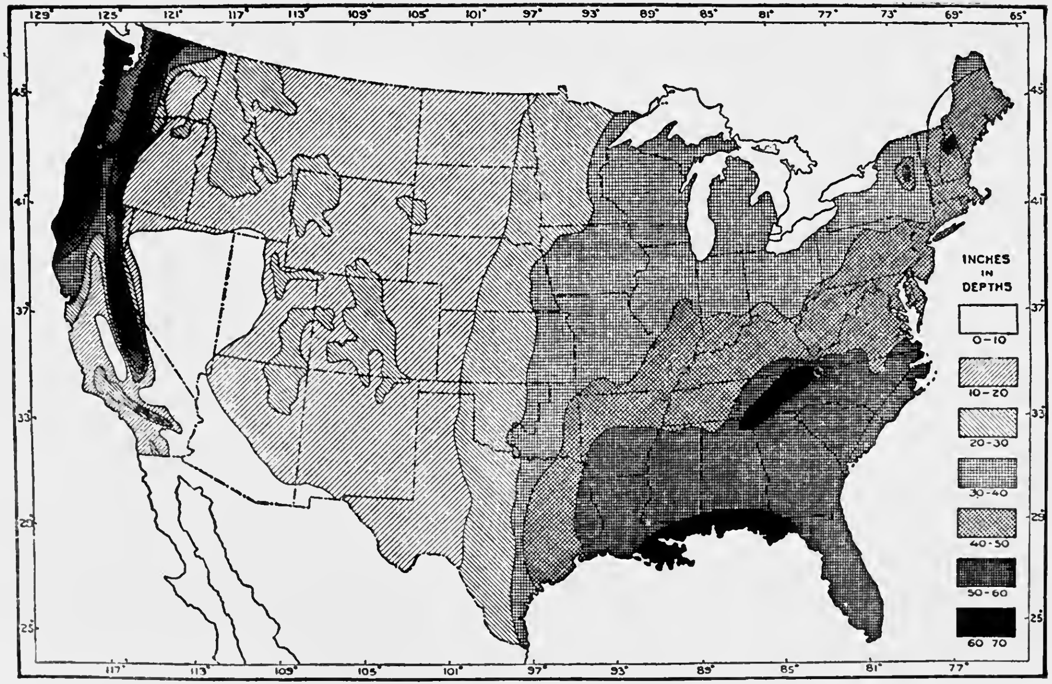
The average size of irrigated farms in arid America is 67 acres. Practically two-fifths of the United States is arid. The dryest and warmest state is Arizona. There is no sharp line between arid and semi-arid conditions; in dry seasons most of the plains west of the Missouri are arid or semi-arid, while in wet seasons the humid area encroaches upon this. A belt of country which is neither arid nor humid extends through North Dakota, western Nebraska western Kansas, Oklahoma and central Texas. This is called by some the sub-humid, by others the semi-arid region. It comprises over 300,000,000 acres. In wet seasons it produces good crops without irrigation.

In general, a country is said to be arid when it has an average rainfall of less than twenty inches. The arid region of North America extends into Canada and Mexico. Only a small portion of this, about 70,000,000 acres, is desert, contrary to the common notion in the East. Most of it supports more or less vegetation; 120,000,000 acres are lightly timbered and 470,000,000 acres are grazing land.

The number of acres of arid land in the United States which it is possible and practicable to irrigate can be stated only approximately. Mr. Meade writes: "A few years ago 75,000,000 acres was a quite common estimate, but most of those familiar with the arid West now make their estimates smaller. There is at present a strong tendency to use less water than was formerly used and as the demand for agricultural products increases greater expense in securing water can be borne. These two influences would tend to increase the area which can be irrigated with the existing water supply under present practice, and any statement as to the ultimate extent of land which can be irrigated is little more than a guess."

OBJECTS OF IRRIGATION

The chief occasions for irrigation are an irregular or an insufficient rainfall. The former is characteristic of most all parts of the United States; the latter is found mainly in western United States. Most of the irrigation in this country is for the purpose of remedying an actual deficiency in rainfall, but much of it would be unnecessary if the rainfall came at an opportune time. The time when crops need water most is in summer and if it is not



79. MAP OF THE MEAN ANNUAL RAINFALL IN DIFFERENT PARTS OF THE UNITED STATES (After Newell)

Note the arid region, from 0-20 inches; the semi-arid region, from 20-30 inches; and the humid region, 30 inches and above. About two-fifths of the United States is arid, and needs to be irrigated

80. IRRIGATING OLIVES, FRESNO, CALIFORNIA, BY CHECK SYSTEM
Note construction of distributing ditch

81. THE INTAKE OF THE SUNNYSIDE CANAL, YAKIMA VALLEY, WASHINGTON
Note the head-gate. These large canals are usually built by corporations or partnerships of farmers

to be had at that time it profits nothing that the soil is replenished with moisture in winter, unless it can be husbanded by the methods of "dry farming."

Irrigation to Enrich the Land.—A secondary object of irrigation, in some cases, is to carry to the crops fertilising material dissolved in water. In sewage irrigation this is the principal object; but fields are often flooded with the water of rivers chiefly for the purpose of enriching them with the fine soil and plant food held by the water. Even though the water of a stream may seem quite pure and be very acceptable for drinking, it may contain sufficient plant food in solution, or in the mud it carries, to make it worth while to distribute this water on land solely for the sake of securing the plant food it contains, which is mostly left in the soil when the water evaporates or seeps down. Many meadows in England and Scotland are irrigated chiefly for the fertilising value of the water. Occasionally, also, the fertilisers that are to be applied to irrigated land are dissolved in the water and distributed by it.

Another object is to correct "alkali." Occasionally irrigation is practised to change the texture of the soil, as, for example, to fill an open, sandy soil with the sediment of a muddy stream. But the chief and almost the only object of irrigation in this country, as applied to farming, is to supply water, with the incidental benefit of adding fertility.

HOW FAR THE NATURAL SUPPLY OF WATER WILL GO

How dry a region or a soil must be in order to make irrigation necessary, or in other words, the least amount of moisture that a soil must have in order to grow a profitable crop, varies widely in different parts of the country, and with different soils in the same section. It depends upon the minimum amount of rainfall, the nature of the soil and especially of the subsoil, the contour of the land and the kind of crop.

The amount of water actually used in the growth of the different crops is capable of fairly accurate calculation. For example, it is estimated that it requires at least four and one-half inches of water per acre to produce fifteen bushels of wheat, nine inches to produce thirty bushels, and so on. These seem like small amounts, but, as has been shown in Chapter IV, a large proportion of the rainfall is lost, chiefly by surface drainage, by evaporation and by leaching, so that scarcely half of the water that falls upon a soil may become available for crops. Hence at least eight to twelve inches of rainfall are needed to produce a profitable crop of wheat, although the wheat uses less than half of it.

It is not enough, however, that the amount of rainfall should come up to a certain standard. If it does not fall at the right time, even larger amounts of rainfall do not save a region from the necessity for irrigation. Moreover, if the soil is not retentive a rainfall considerably in excess of the amount needed to produce a crop on a more retentive soil will not avail. Most of the arid area of the United States has a rainfall of about ten or twelve inches, but there is a wide variation in the time when most of this falls, and the ability of the various soils to hold it.

There is a large area in the West where dry farming, which is the profitable culture of crops in an arid or semi-arid region without the aid of irrigation, is notably and increasingly successful. Dry farming is discussed in Chapter V. Thus the farmer of the semi-arid Palouse region, in eastern Washington and eastern Oregon, is able to grow much larger crops of wheat than the farmer in other regions having the same amount of rainfall, because most of the rain falls in winter and early spring, and is practically all absorbed by the soil as the weather is cool and there is little evaporation; whereas, if a large portion of it fell in summer the loss by evaporation would be great. Then again, the soil of this region—a deep basaltic ash—is remarkably retentive of moisture, drying out very slowly and giving up its moisture gradually to crops during the almost cloudless summer.

This single illustration will emphasise sufficiently the importance of these points in their relation to irrigation; that the need of supplying more water to a soil in order to make it produce profitable crops depends not only upon the actual amount of rain, but also upon the time when it falls, upon the retentiveness of the soil, and upon the skill of the farmer in making the fullest use of the natural supply of water. Ten inches of rainfall in one section may be equal to sixteen inches in another, so far as its crop-producing capacity is concerned.

IRRIGATION IN HUMID REGIONS

In the United States irrigation is resorted to chiefly as a means of correcting an absolute deficiency of moisture. It is an arid and semi-arid farming practice and is confined mainly to regions having less than twenty inches of rainfall. But there has been much interest in irrigation in the humid sections of the country. Many small irrigation systems are in profitable operation in the Eastern States, aside from the large areas of rice and cranberries that are necessarily irrigated by flooding.

The reason why it sometimes pays to irrigate, even when the annual rainfall is forty to sixty inches, is because of the frequency of serious droughts during the growing season, especially at the time when the crop is approaching maturity. Over a large part of eastern United States protracted summer droughts are common, and often reduce very seriously the yields of crops. It is argued that if the crops could have a few irrigations at these critical times the gain in yield would more than pay for the cost of establishing the irrigation plant. This contention has been fully established in many cases. The construction of an irrigation plant in a humid region may be regarded as an insurance against unfavourable weather that may or may not come. There is seldom a season when the rainfall in any part of humid United States is so abundant and so evenly distributed that one or more irrigations would not materially increase the yield. The almost universal watering of lawns and gardens from the hydrant is irrigation on a small and expensive scale, yet this usually pays.

The question, however, is not whether any benefit would be derived from irrigation, but whether the benefit is commensurate with the cost, and whether nearly as good results could not be secured, and much more cheaply, by better methods of tilling the soil to husband rainfall. Irrigation in a humid climate may easily become a cloak for shiftless tillage. Undoubtedly there are many cases when it will pay to irrigate in the East, especially certain water-loving crops, as strawberries, celery, raspberries, blackberries, grass, and garden vegetables. In the East, however, it is a question of economics, not of necessity, as it is in many parts of the West; the point is whether the increase in crops will pay for the extra expense. That depends upon the character of the soil, the value of the land, its nearness to market, the ease with which water may be secured and distributed, and many other business details. To illustrate: It might pay to irrigate grass land in Connecticut, which has about forty to fifty inches of rainfall, if there is a stream from which water can be easily diverted and cheaply distributed; but it might not pay to build an expensive storage reservoir for this purpose. It might pay to irrigate a market garden on high-priced land close to the city, on which the value of the crops may reach \$300 to \$700 per acre, when it would not pay to irrigate the same crops grown on cheap land. It must be remembered, also, that irrigation can rarely be practised in the East as economically as it can in the West, because there the land has a fairly uniform surface as a rule, while Eastern farms are much more frequently irregular in contour and difficult to irrigate. Moreover, it is easier to hire skilled irrigators in the West than in the East. Most Eastern irrigation, aside from cranberry and rice, is on market-garden crops in the suburbs of large cities near the Atlantic seaboard.

As a general proposition, then, irrigation in humid sections is a matter of expediency; it may pay or it may not, according to the conditions. It is an entirely different question here from what it is in arid regions; there irrigation is the only way to make farming pay. One disadvantage of irrigating land in a humid climate must not be overlooked; it is the danger of a heavy rain coming after an irrigation, flooding or soaking the land. This condition never arises in an arid country. If the soil is heavy and tenacious this is a serious objection; but if it is sandy or loamy, so that water quickly drains from it, there is little danger of injury and these are the Eastern soils that are usually benefited most by irrigation. The cost of building irrigation systems should usually be less in a humid region than in an arid region, because the supply of running water is larger and more widely distributed, but the cost of applying the water is usually greater. The diverting of water from Eastern streams, however, is attended with much uncertainty, because of riparian rights, which are firmly adhered to in the humid East, but usually set aside in the arid West. This fact has discouraged many attempts to build irrigation systems in the East. However, springs can be utilised and most irrigation on a small scale in the East is by pumping from springs and wells.

It seems likely that the advantages of irrigation in the humid sections of our country have been over-estimated. In a majority of cases better preparation of the soil before planting, so that it will hold more water, and more thorough tillage of the soil after planting, so that little water will be lost by evaporation, are likely to be a more practicable solution of the drought question than irrigation. In other words, the principles of dry farming are likely to be as successful in mitigating the effects of drought in humid sections as they are in making the most of a scanty rainfall in semi-arid sections. Better tillage, rather than more water, is the key to the drought situation in the

East, except, perhaps, in the special cases noted above.

SUPPLY OF WATER FOR IRRIGATION

The most common source of water for the large irrigation systems is a river or smaller stream. It is extremely fortunate that most of the arid sections of our country are traversed by streams which have their origin in highlands, where the rainfall is much greater than in the plains, and so the streams are never-failing. Some western streams, notably in southern California, do not appear on the surface except in freshets. They exist below the surface, however, in a very real sense, as a well defined body of water, seeping through the soil in a definite channel. Such streams may be dammed below the surface and used for irrigation; or wells may be sunk in or near the dry river bed and the water pumped up. Innumerable wells have been sunk in southern California for this purpose, especially during the recent series of years of extremely scanty rainfall, ending in 1900.

Occasionally lands are irrigated from a lake or pond, but more frequently from a special storage reservoir made by damming a stream. Some of the most notable irrigation systems in the West are supplied by masonry reservoirs built at a great cost. It is a part of the Government's plan, under the Reclamation Act, to build immense reservoirs among the foothills for storing the water derived from the rain and melting snow on the mountains. Whether covering a few acres or many square miles, these reservoirs are constructed at strategic points, as in a natural depression, like a deep, narrow valley or cañon having only a narrow opening at the lower end which would need to be closed.

Irrigation Water from Springs and Wells.—Irrigation from springs and wells is of far greater importance in India and in parts of Africa than in the United States; most of our irrigation is done from streams. In eastern United States, however, it is frequently practicable to supplement the deficient rainfall of certain seasons by supplying water from a well or spring, provided the area to be covered is not large. In India a single well waters, on an average, from 3 to 5 acres of arid land. Small springs yielding only two or three quarts per second may be cleared out and should irrigate several acres. It is usually necessary, however, to provide a reservoir when the flow is so small. This may be merely large enough to hold the flow of twenty-four hours. A spring that runs two quarts per second would discharge 43,200 gallons in twenty-four hours, which could be held in a reservoir forty feet square and three and one-half feet deep.

Spring and well water is sometimes too cold to be used for irrigation until it has been first warmed in a reservoir, but this is not usually necessary; and since it contains far less plant food than stream water, and is usually more difficult to secure, it should not be used for irrigation when any other can be had conveniently. Wells can be had in most parts of the arid regions at a depth of 20 to 100 feet. The water is usually raised by a windmill. Artesian wells—those in which the water comes up and overflows the surface of the ground—are sometimes available for irrigation, notably in South Dakota.

Use of Hydrant Water for Irrigation.—The use of hydrant water for irrigation is confined to market and home gardens near cities and large towns, especially in the Atlantic States. It can usually be bought in quantity at twenty to thirty cents per 1,000 gallons, at which price it may sometimes be practicable to use it for forcing a high development of crops on high-priced and heavily taxed land. The market gardeners around Boston, New York and other Eastern cities quite frequently resort to hydrant irrigation; but this method is entirely out of the question for the general farmer living within city limits.

THE CONSTRUCTION OF SMALL EARTH RESERVOIRS

The construction of large irrigation canals and reservoirs is a problem in engineering, not in agriculture, and will not be considered here.

A large proportion of the small irrigation plants, especially in the humid states, make use of an earth wall, as a dam to a small stream at the mouth of a valley, or across a gully to catch and hold surface drainage, or as the sides of a reservoir built upon level land and filled by a windmill, hydraulic ram or steam or gasoline pump. Such a reservoir should be placed high enough to water all the land, but if it is filled by power it should be as low as possible so as to save the lift. Loosen the ground with a plow where the walls are to stand and saturate the soil with water. When it has dried somewhat let the teams pass over it often. Repeat the wetting and tramping as the wall arises. Almost any loam or clay soil will hold water if it is puddled in this way. If the soil is fairly stiff and the reservoir small this puddling may take the place of the clay wall that is necessary for large reservoirs.

The bottom of the reservoir should then be harrowed, and, if necessary, covered with clay and puddled.

The banks of small reservoirs should have a rise of not more than one foot in two. The top of the bank should be at least two and one-half feet wide. For example, if a bank is five feet high it should be about seventeen feet wide at the base. The rim of it should be sodded or faced with stone to prevent erosion by waves. A circular shape is preferred because it requires the least number of feet of wall to inclose a certain area, and seepage is less. The outlet should be just above the bottom and may be masonry, a plank sluiceway, sewer pipe or wrought-iron pipe, according to the size of the reservoir. It should be provided with a gate. The loss of water by seepage from these small reservoirs varies with the character of the soil, but need not exceed eight inches a year and is usually less. The loss by evaporation is usually much greater, especially in very dry or windy climates. It can be lessened only by planting windbreaks.

PUMPING WATER FOR IRRIGATION

Most of the irrigation in this country is done by diverting water from streams or reservoirs by gravity. In most cases this is the only kind of irrigation that is at all practicable. But occasionally it is necessary or expedient to raise water from the supply to the main ditch or to the field. This is done chiefly by windmills, engines, hydraulic rams, water-wheels. Pumping water for irrigation has become quite common in California, where wells are sunk in or near the beds of underground streams. There are over 200,000 acres in California irrigated from wells, the lift in many cases being over 200 feet.

Windmills.—The most common source of power for moving water is the windmill. When small areas are to be irrigated, and it is not necessary to raise the water over 25 feet, a windmill can often be used to advantage. It is first necessary to be assured of sufficient wind during the growing season. Fortunately, the arid and semi-arid prairies and valleys of the West are usually windy. In the East, especially in a hilly country, it is sometimes necessary to secure an exposed site for the windmill, as a tower 70 to 90 feet high, above hills, trees and other obstructions. The windmill should be able to utilise all the power in winds of from 8 to 30 miles an hour, according to the size of the machinery. For the best service it should have two pumps, one of smaller capacity than the other, and should be so adjusted that each may be used alone, or both together, according to the strength of the wind. Small, rapid windmills, having wheels 8 to 12 feet in diameter are usually considered most economical. According to the Office of Experiment Stations a good windmill will irrigate from ½ to 7 acres of land at a cost of .75 to $6 per acre. But there are many crude, home-made windmills that do fairly good work, costing from $5 to $25, being made of old mowing machines, dry goods boxes and bale wire. These have enabled many a poor settler to get a start the first few years.

The water may be drawn from a well, stream, pond or lake. In many parts of the arid region water may be struck from 20 to 50 feet deep and an unfailing well secured, from which water may be raised for irrigation. But it is absolutely necessary first to provide a reservoir; little can be done with the small stream pumped direct from the well. The storage reservoir or tank may be of wood or other material, but usually the most practicable method is to build one of earth as already described. Sometimes two or more mills are placed around a reservoir of this kind.

Steam and Gasoline Engines.—This power is used chiefly by market gardeners in the East for irrigating small areas, when the height to which the water must be raised is not over 20 feet. There are many makes and styles of engines adapted for this purpose. Gasoline engines are commonly used when coal and wood are very costly. A 2-horse-power gasoline engine should irrigate an acre at a cost for fuel of about 50 cents a day. The cost of pumping water by engines usually exceeds the cost of maintaining ditches or the price of water bought from a canal company. King found that a 2½-horse-power gasoline engine could pump sufficient water to cover an acre 12 inches deep for $3.75 per acre, and that it could easily irrigate 10 acres 12 inches deep without a reservoir. The same authority determined that an 8-horse-power portable engine, with soft coal at $4 per ton and with a lift of 26 feet, could draw water through 110 feet of 6-inch suction pipe and discharge it through varying lengths of the same pipe up to 1,200 feet at a fuel cost of 18.1 cents per inch of water per acre, or $2.17 per acre for 12 inches. The expense of pumping is rarely below $3 an acre per season, and often twice or thrice that amount.

Gasoline pumps range in capacity from 5,000 gallons per minute from a depth of 25 feet down to 300 gallons per minute. Centrifugal pumps run by steam are quite commonly used up to 40-horse power and sometimes larger. Most of the smaller pumps are run by gasoline. These pumps draw water easily from a depth of 100 to 400 feet. This method is practicable chiefly in the humid and sub-humid regions and for small operations, but rarely in an arid country and for large operations. Gasoline engines are often used to supplement wind power, being used to run the pump on still days.

Water-wheels.—One of the oldest and still one of the most useful means of carrying water to thirsty land is by utilising the force of flowing water. When a stream has sufficient fall to develop water power this is one of the cheapest and most satisfactory methods of irrigating small areas. There are thousands of water-wheels on the edge of swift-flowing streams in the arid West, and hundreds of thousands in Europe and Asia.

The undershot is one of the oldest and best of water-wheels. This is a paddle wheel carrying buckets on its rim, so that when the current turns the wheel the buckets are filled, raised to the top and emptied automatically into a wooden flume which carries the water into the irrigation ditch. These undershot wheels are of many patterns, and may be as much as 35 feet in diameter. The largest may supply nearly 120 acres with 2 inches of water every ten days.

On the other hand, the water-wheel may be used to drive a centrifugal pump which develops power to lift other water out upon the land. This method is especially useful when the stream has a high bank along which canals could be built only at great expense. The Wyoming Experiment Station describes a wheel 10 feet in diameter and 14 feet long, which is connected by a sprocket wheel and chain to a 3½-inch centrifugal pump, which lifts 1,000 gallons per minute to a height of ten feet. It irrigates 200 acres at the rate of 2½ inches every 10 days, and costs $1,200.

Hydraulic Rams.—Large hydraulic rams are often serviceable for irrigating small areas. They are cheap and they work for many years with practically no attention. A large modified ram known as a siphon elevator, is said to be capable of lifting 6 acre-inches under a head of 10 feet to 25 feet high in 24 hours, or enough to irrigate 24 acres 2½ inches deep every ten days. This can be used only when there is a reservoir, and costs about $500.

In Europe and Asia various crude devices for using horse, mule and man power are often used to lift water for irrigation. These are for the most part entirely unnecessary and impracticable in the United States, being too slow and laborious; but from these humble beginnings many prosperous irrigated farms have been developed in the arid and semi-arid regions of our own country.

DISTRIBUTING THE WATER

Water is diverted from the main canal into the farm laterals, and from these into smaller supply ditches, through a sluice-gate made of boards or planks. These are of many styles, but the essential principle in most of them is a rectangular flume or sluiceway with a wooden shutter, mortised into the upper end, which can be raised and lowered in its groove. In diverting water from a ditch the covered sluiceway is carried through the bank nearly on a level with the bottom of the ditch and the gate is placed at the ditch end. The joints of the grooves should be tight so that no water will trickle through; sometimes they are faced with rubber or leather. Besides many styles of these home-made gates there are various manufactured gates which are more complicated.

Distributing Ditches and Flumes.—Having brought the water to the farm by ditch, flume or pipe, it must now be distributed to different fields. This is usually done by taking out from the main-supply ditch smaller distributing ditches or laterals, which should have a slight but uniform grade. Generally it is best to run these main laterals direct to the different fields, from the point where the water is delivered, and to take from them small laterals to all parts of the fields. The main lateral or "head-ditch," is located on the border of the fields, if the land is nearly level; or on the ridges, without regard to field lines, if the land is rolling. They are usually permanent. Laterals for flooding should be 50 to 100 feet apart. Laterals for furrow irrigation are farther apart, usually from 20 to 50 rods and run across the direction of the furrows, so that water can be turned into each furrow at its head. These small laterals may be permanent or temporary. Distributing laterals should be run nearly at right angles to the greatest slope of the land. A fall of at least five feet per mile is commonly recommended and twenty-five to thirty feet per mile is not uncommon.

Small laterals are quickly built with a mouldboard plow by turning up two parallel furrow-slices with unbroken ground between them. The bottom of the ditch should be on a level with the surface outside, so that water will flow out of it when the bank is cut. In other words the banks must be made of soil that is mostly taken from outside the ditch, so as not to lower its bottom. Double mouldboard plows and special "lateral plows" are also used. When it is necessary for a distributing ditch to cross over a small depression it must be built up by heaping firmly tramped soil into a high pile, in the top of which the water course is cut.

If the depression is deep it may be more expedient to carry the water across it in a wooden flume, built of two planks, like a V, or square-bottomed. In arid regions ditches are used almost exclusively for distributing water from the main supply, being cheaply built and easy to handle.

The loss of water from lateral ditches by seepage is great, especially on open soils; were they not so cheap they would be impracticable. Pipes carry the water to its destination with no seepage, with no evaporation and with great celerity. Their expense is against them for general use in arid regions but in the Eastern States they are often used to advantage in small operations, especially in market gardening. Board flumes are perishable and permit of evaporation, but they are cheap and are usually the most practical means of distributing water if the ditch will not answer. The best flume for carrying a small amount of water is a V-shaped trough made of two boards nailed together and bedded in the soil, with short cross pieces under the end joints. If pipes are used they had better be laid on the surface and removed in the fall.

The use of cement-lined ditches for distributing water, in the arid regions and elsewhere, is increasing. If the soil is stiff and the region is not subject to hard frosts, cement or asphaltum may be laid directly upon the bottoms; but usually it is safer to provide some foundation for the cement, preferably flat stones. The advantages of a cement-lined ditch over an ordinary one are that it prevents seepage and washing and carries the water to its destination quickly, so that little is lost by evaporation. Such ditch linings are not safe except in mild climates as they are likely to be heaved by hard frosts.

Whatever the method of distributing the water it should be carried along the highest part of the field to be irrigated. From this head ditch the water is applied to the land by gravity.

METHODS OF APPLYING WATER

The methods of securing, storing and distributing water are largely matters of engineering, although they have a direct and vital relation to successful agriculture on many American farms. The point is now reached when the water must be applied to the soil; here agriculture begins. The problem of securing sufficient water to water the farm economically is often very difficult, calling for much ingenuity and engineering skill. But the problem of applying this water to the land, so that both soil and crops will receive the most benefit, is much more complex. The engineer can help the farmer bring water to the farm successfully and economically, but the problem of how best to use this water on the land each farmer must solve in his own way.

The use of water, like the use of fertilisers and manures, is not capable of being formulated into definite rules applicable for all farms, or even for any considerable number of farms; chiefly because the soils of few farms are exactly alike, or have been cropped alike. Irrigation has been practised for hundreds of centuries, yet there is no generally accepted body of information on the best way to use water. This must be left largely to the judgment of the farmer. So there are good and there are poor irrigators, according to ability to judge correctly the nature of the soil and the needs of the crop. One man is able to make an inch of water go twice as far as another. Some souse their crops and puddle their land; others know how to let the soil dry out and sweeten until the critical time comes when the crop would suffer if water were not added. Like tillage, irrigation is a matter of judgment, not of rule.

The principal methods of applying water are by flooding, by furrows, and by sub-irrigation. The method of applying water to the land is governed by the kind of crop and the texture of the soil and of the subsoil. If the soil is coarse-grained water will sink down rapidly and much will be lost by seepage if it is allowed to stay upon the soil long in the same place, as in furrow irrigation. Coarse-grained soils should be flooded, if expedient.

FLOODING

The simplest way to use water is to spread it over the surface, as a river overflows its banks. If the land is fairly level this is the cheapest method of wetting a large field before it is plowed for planting and also for watering land used continuously for grains, grasses, clovers and other crops that are not tilled. But an almost perfectly level field is rare; so, in the contour check system of flooding, it is usually necessary to throw up low banks, or "levees." These are built at right angles, forming square or rectangular blocks of land of from ½ to 20 acres, depending upon the contour, the head of water, the crop, and the height of the banks. On land that has a marked slope a common size is 50 to 150 feet square, but sometimes checks only 2 or 3 rods square are necessary. In the San Joaquin Valley, California, 30,000 acres of alfalfa in one block are irrigated by flooding. The banks are 12 to 20 inches high, 12 to 18 feet wide at the base and are plowed, harrowed and harvested like the enclosed spaces.

When the field slopes considerably in but one direction, the checks are made rectangular instead of square with the long sides running across the slope. This makes it possible to include a larger area within the check. If the slope is uneven the banks running across it will naturally have to follow the contour. They are from 10 to 20 inches high and 4 to 15 feet wide at the bottom, so that mowers and harvesters may be driven over them easily. Thus they become permanent features of the farm. The ridges may be thrown up by hand with shovels, but usually by plowing in back-furrows and using a scraper the work can be done more economically. Each check should include as large an area as possible of approximately the same level.

Filling the Checks.—In flooding a field it is customary first to turn the water into the highest check and after this is saturated to open the bank between it and the next lower check, and so on, all the checks being flooded in succession from higher to lower. Or the water may be taken down between the lines of checks and turned in on each side, flooding the checks in pairs. Or all the upper checks may be irrigated at the same time, and the water drawn off into the next lower checks simultaneously. Instead of cutting the bank there may be ditches with head gates between all the checks. Obviously the water stands deeper on the lower side of a check than on the upper; the more the slope the greater the difference. Thus if a field slopes 8 inches in 300 feet, in order to give the soil on the upper part of a check 300 feet wide 2 inches of water, the water would have to stand 10 inches high at the lower bank. Build the banks at least 3 inches higher than the water will stand on them.

Wild Flooding.—Another system of flooding quite commonly practised in the West, is to cover the field with a thin stream of running water; this is sometimes called "wild flooding." It is practicable only when the slope is quite moderate and uniform. Deep furrows are plowed down the slope 50 to 125 feet apart or following an easy grade. A V-plow is used which throws the earth both ways, making a ridge on either side that throws the water outward. Water is diverted into these furrows from the head ditch and each furrow is dammed at a suitable distance merely by a piece of canvas fastened to a 2 x 4, which is laid across the furrow and the edge of the canvas held down with soil. The water backs up in the furrows and overflows across the intervening spaces. When the soil is sufficiently wet the canvas dams are moved farther down the furrows. A wooden or metal "tappoon" is used for this purpose in California and Arizona, being thrust down into the soil so that it obstructs the furrow. The furrows may be temporary, when tilled crops are grown; or permanent, when sod and grain crops are grown. All the water will not soak into the ground; some will flow into the depressions, from which it is directed into the other furrows. The furrows are not necessarily parallel; they follow the contour, making really a series of checks not bounded by levees. The canvas dam is often dispensed with.

In all systems of irrigating by flooding it is often necessary and practicable to level off small inequalities before applying the water. There are many styles of levels and scrapers, both home-made and patented, which answer the purpose. One built of two braced 2-inch planks, forming the letter A, does very well if weighted and shod with steel strips.

FURROW IRRIGATION

When the land has too steep a slope to be flooded advantageously, and when crops are grown that do not cover the ground and must be tilled, it is usually best to irrigate by furrows. The furrow system is also used very commonly on land that could be flooded, and for sown crops as well as for hoed crops. On steep land the furrows may be permanent, either for a number of years or for one season, but they hinder cultivation. Temporary furrows are best in most cases. If the soil needs watering before planting, however, it is customary to irrigate by flooding until the soil is wet at least four feet deep. The crop is then grown as long as possible without irrigation by giving it thorough tillage, for four feet of wet soil should contain six to eight inches of water.

When irrigation becomes necessary take water from the supply, which runs along the highest point of the field. This may be a head ditch, or a wooden or cement flume, with holes an inch or more in diameter at the end of each furrow, plugged when not in use. A wooden flume is commonly made of soft redwood timber, 16 feet long and 8 inches wide, with collars 2 x 3 inches every 8 feet—one in the middle and one at the joint. In garden irrigation on a small scale a wooden V-shape flume may be placed at the head of the rows and the water may be drawn through small holes cut into the sides or top of the flume and furnished with plugs.

Plowing Irrigation Furrows.—The furrow may be plowed out with one of the many special irrigation plows, but a shallow-furrowing plow will answer. The furrows should run in such a way that they follow the contour, so as to enable the water to barely trickle down to the ends of the furrows without washing. If the slope is quite sharp the rows of plants and the irrigation furrows must run diagonally across the slope from the head ditch. Water is turned into several furrows at once; when it has reached the ends of the furrows it is shut off at the head ditch and more furrows are filled.

The amount of water that the soil receives depends very largely upon the grade of the furrows. If it is slight, the water moves sluggishly and more sinks into the soil before it reaches the end of the furrow than if the furrow is sharp. Do not allow enough water to enter the furrows to overflow them. The water is distributed from the furrows sidewise all through the soil by capillary action. It creeps from particle to particle until it meets the water spreading sidewise from the adjoining furrow.

Distance Apart and Length of Furrows.—The best distance apart for irrigation furrows depends upon the nature of the soil and the demands of the crop. The looser a soil is the closer they should be. Water spreads slowly in heavy soils, but sandy soils are leachy. They may be between every two rows of potatoes, corn, sugar beets, or other row crops, or between alternate rows; but in the latter case the furrows for the next irrigation should alternate with those of the previous watering. As a rule the furrows should be from 4 to 6 feet apart. Hilgard shows that water may be applied in wide furrows much more efficiently than in shallow furrows because there is less evaporation and the surface is not wet as much. A few wide, deep furrows are better than many narrow, shallow furrows. The distance which it is possible to send water along a furrow, and thoroughly wet all the soil, depends upon the grade and the nature of the soil. The more porous a soil is the shorter should be the furrows. Water is commonly sent from 20 to 75 rods in furrow irrigation and sometimes over 100 rods.

After a field has been irrigated, and the surface has dried, the furrows are levelled with the cultivator. This is set to work as soon as possible, so as to break up the crust, which indicates the rapid loss of water by evaporation. The surface mulch on an irrigated soil should be much deeper than on soils in humid regions; four inches is barely enough, and six inches is often necessary.

A modified form of furrow irrigation is sometimes practised on grain fields by rolling the field after sowing with a "marker," which is simply a roller having parallel ridges upon it so that it makes shallow grooves or furrows on the surface. The roller is run in the direction that will give the right slope for applying water. Water is turned into these small furrows as into larger furrows. Grain fields are more commonly irrigated by wild flooding. Furrow irrigation is used almost exclusively for fruits and farm and garden crops that require inter-tillage. In many places it has supplanted flooding for watering grains and grasses. It is the dominant system of irrigation in America to-day.

SUB-IRRIGATION

The great loss of water by evaporation under surface irrigation, and the inconvenience of having the surface broken by ditches and furrows, has led to many experiments in applying water below the surface through tiles, perforated iron pipes or perforated cement pipes. Theoretically sub-irrigation is vastly superior to surface watering; the surface is undisturbed, the soil is not puddled as it sometimes is in surface watering, no water is lost and it is all applied just where it is needed most—beneath the surface mulch of dry soil. But sub-irrigation has been found impracticable in most cases where it has been tried. The one great difficulty with it is the cost, which is usually out of all proportion to the benefits. It costs from $60 to $90 an acre to equip an average field for sub-irrigation with drain tile if the lines of tiles are placed from four to seven feet apart, as is usually necessary. This outlay cannot be justified except, perhaps, on high-priced land, and especially land used for market gardening.

Another great difficulty with sub-irrigation, in some cases, is in being unable to supply sufficient water to wet the surface soil thoroughly, owing to the poor water-moving power of some soils. Some soils are so porous that if water is applied to them eight or ten inches below the surface, more of it will be lost to the crop by downward leaching than would be lost by evaporation if it were applied on the surface.

Three-inch drain tiles are, on the whole, most useful for sub-irrigating. They are usually laid from 5 to 24 inches below the surface and from 4 to 12 feet apart, according to the openness of the soil. Rarely is all the soil wet economically when the lines of tile are more than 6 feet apart. Usually each joint is closed with cement, except one or two inches on the under side. They are laid like tile drains, and act as drains if the soil becomes too wet. The fall should be very slight. Besides tile, galvanised sheet-iron pipes, with an open seam, and perforated iron pipes are sometimes used. On many soils more water will be required for sub-irrigating than for surface watering, even though there is no loss by evaporation, owing to the slowness with which it moves sidewise through the soil and the rapidity with which it sinks down out of reach of the roots. A very porous subsoil is unfavourable for sub-irrigation.

But there is no use in discussing the pros and cons of sub-watering because the expense of the method is usually prohibitive. Sub-irrigation is now rarely practised except in greenhouses and in a few market gardens. Running water into the upper end of the main of an ordinary tile drainage system has been tried and with some degree of success in rare instances. It is necessary in these cases that the water-table should be nearly on a level with the tiles.

Under sub-irrigation mention should be made of the lands that are watered naturally beneath the surface by underflow, or seepage from higher land. Lands below large irrigation canals, and receiving its seepage, are often sub-watered to such an extent that they become marshy and unfit for cultivation unless drained; in other cases they produce excellent crops without drainage or the need of any surface irrigation. Of the same nature are certain low lands that receive sub-watering from higher land, either near-by or many miles away. The springs and underground seepage from high lands often follow certain strata of rocks and subsoil and sooner or later come to the surface, watering the land at that point uniformly and continuously from below.

METHODS OF MEASURING WATER

The methods of measuring or apportioning water are diverse. It is necessary that they be accurate, especially when the water is purchased, or when several farms are supplied from one ditch. Usually, however, an irrigator receives water not by measurement but by proportion; he is given a certain proportion of the water in a ditch, as one-fifth; and it is not measured by inches, but by proportions of the whole. This is regulated very simply by placing an upright partition or "divisor" in the flume or ditch, one-fifth of the way across, so that one-fifth of the water flows into the sluice-way and the remainder passes on. But the velocity of the water in the ditch is greater near the centre than on the edges, so that those that use the smallest amount of water always get less than they are really entitled to. To correct this the ditch is often broadened above the measuring box so so that it flows through very slowly. If the volume of water is to be halved this is not necessary.

Modules.—When a certain amount of water is to be taken out of a ditch or flume, rather than a certain proportion, "modules" are used. There are many forms of these, from the simple inch-square hole cut in a plank to the complex weirs and patented measuring boxes. No measuring device now known is entirely satisfactory, because of the rapid fluctuation in the height and velocity of water in the ditch. King concludes "the most exact and generally satisfactory way of apportioning water among users that has yet been devised is that of bisecting the stream until its volume has become suitable for individual use, and then subdividing by time under some system of rotation."

Units in Measuring Water.—The amount of water used in irrigation is commonly stated in one of two ways; either the depth of standing water on the surface, or the amount of water flowing through an opening of a certain size during the irrigating season. An "acre inch" is enough water to cover one acre of land one inch deep, which is 27,150 gallons. It is gradually becoming the standard of measurement in this country. A "miner's" inch is the quantity of water that will flow through an opening one inch square with a certain head, usually six inches, from the upper side of the opening. This is about twelve gallons per minute. But the amount of head varies by law in different states. In California fifty miners' inches are equal to one second foot, but in Colorado 38.4 miners' inches equal a second foot. The "second foot" is the unit when one cubic foot of water is discharged each second. It will cover an acre about two feet deep in 24 hours, or 23.8 acre inches, and is sufficient to irrigate from 70 to 100 acres of land during an irrigating season of about ninety days.

DUTY OF WATER

This is the amount of land that it should irrigate. No definite rules can be made on this point, owing to the varying capacity of different soils to hold water and the varying demands of different crops. For example, nearly twice as much water is needed in Arizona as in Montana, largely because the season is longer and the loss by evaporation much heavier. The actual amount of water used by the crop itself is small compared with the amount needed to saturate the soil so that conditions favourable for plant growth are produced. Then there is always a considerable amount of seepage and evaporation which cannot be measured. Much also depends upon the capillary power of the soil, or its ability to draw water upward, and especially upon the water-holding and water-moving power of the subsoil.

In regard to the actual amount of water needed by plants, Professor King has determined that it takes from 300 to 500 pounds of water to make one pound of dry matter in the crop. Since an inch of water covering an acre weighs about 113 tons it would require 3 to 5 inches of water to make one ton of hay, corn fodder or other dried crop. This is about the minimum figure and does not allow for serious loss by seepage and evaporation. In southern California excellent results have been secured with 6 or 7 inches per year in years when water was low, but only when the water was used with great economy, and the irrigation was supplemented with excellent tillage. Ordinarily nearly twice this amount is necessary, the average for southern California being about 12 inches, in addition to a rainfall of 10 to 20 inches.

The Character of the Soil.—When water is first turned upon virgin land it takes a large amount to thoroughly wet the soil, especially to saturate the subsoil. Newell states that on some arid soils 10 feet of water is often needed the first year and 5 feet or more per year for two or three years thereafter. As the subsoil becomes saturated and the water-table raised, less and less water is needed, until 8 to 18 inches per year or less may be sufficient.

The amount of water needed for a single irrigation varies from 2 to 4½ inches, according to the openness of the soil and the crop. If the soil is very dry, however, as on virgin land, two or three times this amount may be needed to thoroughly saturate the soil to a depth of 4 or 5 feet. If the soil is clayey and cracks badly, smaller and more frequent irrigations are better, since less water is lost by leaching through the cracks.

The Kind of Crop.—The deeper the roots of the crop feed the more liberal may be the irrigation. What is desired is to store as much water as possible in that part of the soil which is laid under tribute by the plants. The deeper a crop feeds the higher is the "duty" of water, or the area that it ought to irrigate, because less of it is lost by leaching, as it is when applied to shallow-rooted crops. In arid regions plants commonly root deeper than in humid regions, because the subsoil is likely to be almost as congenial for root growth as the surface soil. Tree fruits of all kinds are deep rooted, also alfalfa; the irrigations of these plants are usually more liberal, but less frequent, than the irrigations of other field crops which do not grasp so much soil with their roots.

The volume of water needed to irrigate an acre in one year may be roughly stated as from 30,000 to 60,000 gallons, which is equivalent to one miner's inch for 5 to 10 acres or one second foot for 250 to 500 acres. It is commonly considered that about the maximum duty of a miner's inch of water is 4 to 6 acres of vegetables and small fruits and 5 to 10 acres of orchard fruits. This means that the ground will be covered from 8 to 16 inches deep in a growing season from May to October. The average for most arid regions is about 12 inches per year. In parts of southern California 30 inches are sometimes used. The volume of water used in sewage irrigation is always much more than this.

The amount of water needed is always dependent upon the amount of rainfall and is an addition to it. The more rainfall the less irrigation, for irrigation should supplement the natural supply. Since the rainfall in a section under irrigation may range from almost nothing to 20 or more inches, and varies from year to year, the difficulty of establishing any definite standard is increased. The season of the year when this rainfall comes has a marked influence upon the quantity of water needed in irrigation. If it comes in summer it is less valuable, as a rule, than winter rainfall.

Levelling the Land.—Arid lands that are irrigated are usually nearly level and are covered with sagebrush. They often have slight irregularities due to the drifting of the light soil. Virgin land must be prepared for irrigation by removing the sagebrush and levelling the surface. The brush is usually grubbed out by hand with a mattock, at a cost of $1.50 to $2.50 per acre. Sometimes it may be plowed out in spring. If a railroad rail is dragged over the field several times, in different directions, the brush can be removed more easily. Sometimes the land is flooded for a year to kill the sagebrush.

It is essential that irrigated land be very smooth so that water will flow readily and evenly. The land is usually first plowed then smoothed with various home-made implements. One of the most common is the "buck scraper" made of two 2-inch planks, 10 inches wide, fastened together and provided with a steel shoe on the lower edge, and with handles for dumping. There are several patented scrapers. The cost of levelling is from $1 to $15 per acre.

FREQUENCY AND TIME OF IRRIGATION

Water should be applied no more frequently than is absolutely necessary for the welfare of the crop. One great danger in irrigation, especially on fine-grained soils, is that of puddling the surface by frequent copious wettings. Then, too, the more often water is applied the greater is the loss by evaporation and seepage and the greater the labour. Dig down 3 or 4 feet in several places and examine the soil. The condition of the soil and of the crops are reliable guides; irrigate before the subsoil gets very dry and before the crop begins to suffer. Plants indicate the need of water by curling their leaves, or the leaves may turn a darker green than usual, or the lower leaves may turn yellow.

There is no uniform practice as regards the number of irrigations. It is usually necessary to irrigate corn, wheat, barley, and oats from three to five times, oats requiring the most water and barley least. In Colorado wheat is irrigated but twice; but sufficient rain usually falls in spring and early summer to make the number of irrigations five or six if all the water had to be applied from the ditch. Clover and alfalfa are usually watered before growth starts in the spring and once after each crop is cut, applying 4 to 6 inches each time. Grass is commonly irrigated as often and as copiously as is expedient without swamping the meadows—usually every ten to eighteen days. Potatoes are not irrigated until blossoming, then two to four times thereafter. Fruit trees are irrigated less frequently but more deeply than field crops; usually two to six times a season, except citrus fruits, which require more water.

When water is plentiful the tendency is to over-irrigate. This is dangerous; too much water is as bad as drought. It keeps the soil cold, air does not circulate in it and the beneficial germs of fertility cannot thrive. The plants look yellowish. If growing fruits, as peaches, they are forced to an abnormal size and are watery, of poor flavour and carry to market poorly. A good irrigator uses as little water as possible. If growing tilled crops the aim should be to make tillage take the place of irrigation as much as possible, for water saved is as good as water added, if not better.

Winter irrigation is becoming quite common, especially in parts of California and Arizona. When the water courses are dry in summer, but full in spring after heavy rains, it is often practicable to divert it to the land and allow it to soak deeply into the subsoil, where it is stored against the drought of summer. If the subsoil is filled with water in winter, little summer irrigation may be needed. Winter irrigation is especially useful as an adjunct to dry farming.

The Time of Day to Irrigate.—The best time to irrigate is late in the afternoon, or on a cloudy day, because less water is lost by evaporation; but the more important consideration of convenience usually dictates the time, regardless of the hour. If heat-loving plants, as corn, are irrigated on a hot, sunny day, the rapid evaporation may cool the soil sufficiently to check growth somewhat. Crops that shade the ground, as fruits and grasses, are not subject to injury in this way. When water is scarce, and can be had only during certain hours, night irrigation is often necessary. This is an economy of water, for less of it is lost by evaporation and the water delivered at night usually costs less than the same amount delivered in the day, but it is difficult to apply it as skilfully.

Directing the Flow.—The flow of the water is directed by a man with a long-handled shovel, with which he keeps certain furrows open or closes them, as needed. It is necessary that the course of the water receive constant attention, for it is likely to collect in the hollows or break the channel. A common mistake in irrigating is to hurry the water, thus increasing the washing of the soil. Let it run so gently that the sides and bottom of the furrows are not washed and the stream runs clear. Too rapid application of water "slickens" or puddles the soil; let it soak in slowly. If the water runs too slowly, direct more of it into each furrow; if it runs too fast, reduce the amount that is allowed to enter the furrow. It requires much practice to become really expert in handling water.

TILLAGE AFTER IRRIGATION

When the crop will permit the land should be tilled after each irrigation. This is especially necessary in the case of orchard fruits, small fruits, corn, potatoes and garden vegetables. Irrigation leaves the surface soil more or less puddled; when this dries it becomes hard and, if clay, it may crack. These conditions are very favourable for a rapid loss of water which, if unchecked, may easily amount in a few days to a large per cent. of the water that has been applied.

Amateurs in arid farming often have a notion that all that is necessary is to irrigate often enough to keep the soil moist, and that tillage is therefore unnecessary. The fact is that tillage is about as important in arid farming as in humid farming. In the first place excessive irrigation makes many crops sappy, over-vigorous and unsubstantial. This is especially true of fruits. In the second place it is good economy to use as little water as is necessary to secure the best results, for water is expensive to secure and laborious to apply. In the third place a soil that is kept as continuously wet as would be necessary in order to grow crops without tillage between irrigations, is not in the best condition for maintaining its fertility. A certain amount of dryness in the surface soil promotes the development of soil bacteria and other agencies that have an important influence on the productivity of the land. As men become more experienced in the use of water they almost invariably decrease the amount applied and increase the frequency and thoroughness of the supplementary tillage. One does not need to grow crops many years in order to learn that there is nothing that can take the place of stirring the soil.

METHOD OF IRRIGATING IMPORTANT CROPS

Methods of irrigating different crops by flooding and by furrows are endlessly varied in different sections to suit the needs of different crops. The following are common methods of handling a few of the most important irrigated crops.

Meadows, Including Alfalfa.—These are irrigated largely by flooding, usually once in early spring before growth starts, and once after harvesting each crop. If irrigation is given more frequently than this, it should be some time before the time to cut the grass, so that the ground may be firm then. Irrigated meadows should usually be cut rather than pastured. Unless the ground has been allowed to become quite dry, animals are likely to roughen the surface and increase the difficulty of flowing water over it evenly. The amount of water used in irrigating meadows cannot easily be excessive. Under sewage irrigation, on the water-meadows of Italy, from 40 to 70 tons per acre are cut each season. These meadows are irrigated by a thin sheet of water running over them almost continuously, night and day, during seven months of the year, amounting to over three hundred feet of water per year. Water is turned off only long enough to cut the six or seven crops of grass, which grows the year around.

Tree Fruits.—Most orchard irrigation is by furrows. The prevailing method is to lead the water through very narrow furrows four or five feet apart, allowing it to soak four or five feet deep and to spread between the furrows beneath the surface mulch before the supply is cut off. It is sometimes recommended that the furrows be run on the shady side of the trees so that the sunlight reflected from the water will not burn the bark and leaves. The water should not actually touch the trunks of the trees; citrous trees are especially liable to be injured in this way, contracting the "gum disease." Water that seeps through at the lower end of the orchard, and which might run to waste, may be collected in a foot ditch and used on the lower land. All the ground on which young trees are planted does not need to be irrigated. A distributing furrow may be plowed four to six feet away from the row of young trees, with branch furrows circling each tree. Water should stand in these from twelve to twenty-four hours. The circle furrow is made farther away as the tree gets older and eventually merges into two straight furrows on each side. The number of the furrows is increased gradually as the orchard comes into bearing until the whole area is laid off with narrow furrows four to five feet apart.

Occasionally fruit trees are irrigated by a system of small pools or checks, a low retaining ridge being thrown up around each tree with a "ridger," and a certain amount of water allowed to stand within until the soil has absorbed it. The chief objection to this method seems to be that it tends to make the roots develop near the surface and close to the tree, and not to forage widely, though it is somewhat more saving of water. More rarely fruit trees are irrigated by flooding the whole ground.

The vital point in irrigating tree fruits is to wet the soil deeply and to make tillage go just as far as it will in reducing the amount of irrigation. In parts of California and Arizona it has been found wise, on some deep soils, to irrigate deciduous fruits —never citrus fruits—in winter, as this may make them less liable to winter injury and lessen the need of irrigation in summer. Late fall irrigation is sometimes practised to prevent fall blossoming and the drying of the tissues of the trees in winter, especially when the rainfall is very scant. Evergreen fruit trees require about 50 per cent. more water than deciduous fruits on the same soil. The only exception to this is the olive, which needs about as much water as deciduous fruits.

Small Fruits.—Raspberries, blackberries, grapes and other small fruits are commonly irrigated by running a furrow each side of a row. Strawberries are so shallow-rooted that they must be irrigated very frequently; hence it is a common practice to lead the water through broad furrows in alternate rows, so that the fruit may be picked between every other row. Depressed bed irrigation is also used for small fruits. This is really a form of check irrigation, only the levees are widened so that water may be carried in shallow ditches along their tops.

Potatoes.—The land should be deeply irrigated before planting and no more water used than is absolutely necessary until after the plants have blossomed. If possible, carry the crop to this point without irrigation. After the vines cover the ground and tubers have begun to form it is exceedingly important that the ground should be kept moist all the time so that the plants suffer no check. It is best to lead water between every two rows, unless water is scarce, when it may be led down every other space, alternating with successive irrigations. The hills should be ridged with a double-winged cultivator so that they will not be flooded.

Garden Vegetables.—These are irrigated by flooding, furrows, and various modifications of both systems. A common method is to make furrows between rows four to six feet apart or in alternate spaces, the water not being allowed to flow outside these furrows. Another method is to lay off the garden into small basins surrounded by ridges four to five inches high and six to eight inches wide. In some cases furrows six inches deep and about eighteen inches apart are made and the plants grow on the high broad ridges between them. Or each row of plants may be set in a narrow basin, with a ridge between rows, the basin being short so that it can be flooded quickly. Vine vegetables, as cucumbers and melons, are commonly grown between irrigation furrows six feet apart, the seeds being planted near the edge of the furrows and the vines being spread on the broad ridge between two furrows. Depressed and raised bed irrigation are also used extensively for vegetables. It is especially important that garden irrigation be followed by cultivation as soon as the ground can be worked.

COST OF IRRIGATION

This depends upon so many factors that nothing at all definite can be stated, as is illustrated in the following general quotations:

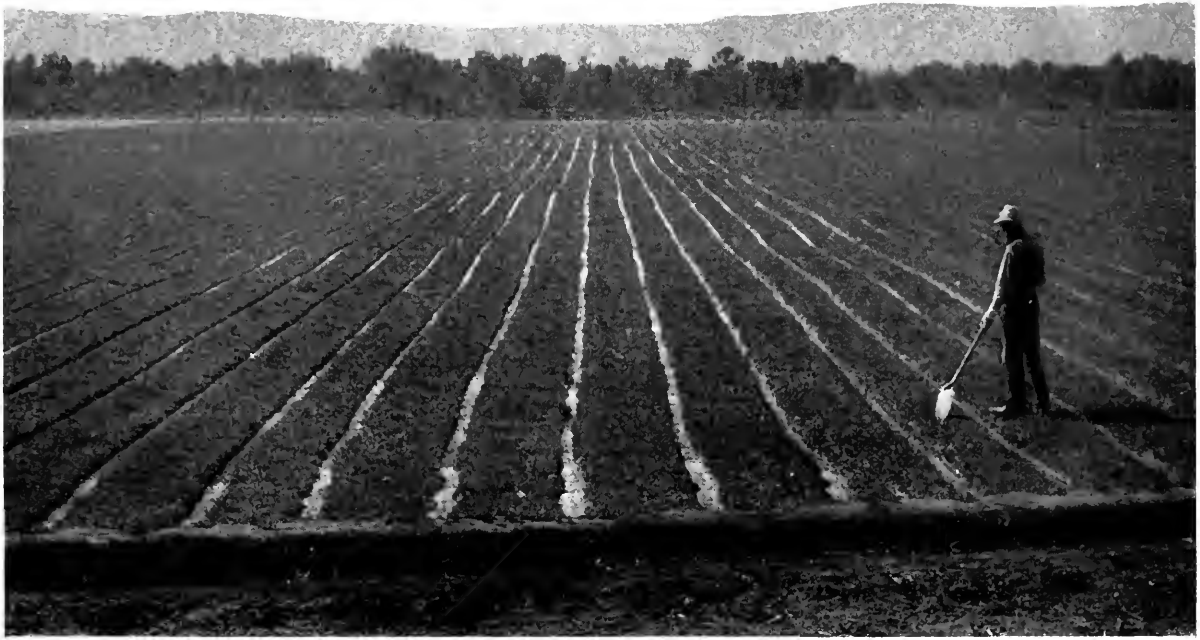
The yearly cost of water in southern California is from $3 to $6 per acre. In Orange County, California, water sells for about $4.75 per acre foot. In Riverside County it cost as high as $15 per acre in the dry year of 1900. In Los Angeles County it was sold from 1898 to 1900 for $18 to $30 per acre foot. Hydrant water bought from a city or

82. IRRIGATING A GARDEN FROM A HYDRANT IN A SEMI-ARID REGION (PULLMAN, WASH.)

A small notch is cut in the wooden flume at the end of each row of celery

83. IRRIGATING STRAWBERRIES BY PUMPING FROM CACHE CREEK, CALIFORNIA

Strawberries require a very large amount of water



84. IRRIGATING ALFALFA BY FURROW SYSTEM, YAKIMA VALLEY, WASHINGTON

Alfalfa is irrigated once after each of the three to six crops is cut.

private water company is likely to cost 20 cents per 1,000 gallons, which is $32.40 per acre for three irrigations of 2 inches each. The average cost of water for irrigating citrus fruits in California is about $10 per acre.

The cost of a water right, which is bought with the land, varies as much as the annual cost of the water. Under the Fresno Canal in California it is about $40 per acre. Census reports show that the average first cost of constructing reservoirs, canals, etc., and bringing water to the land is about $8.15 per acre; while the average cost of maintenance is about $1.10 per acre. Irrigation in the humid states usually costs more, largely because Eastern farmers have not the skill and the economy in handling water that comes natural to one born in an arid region. The average cost of irrigation in Connecticut in 1899 was $34.21 per acre, which is about four times the average cost of irrigation in arid regions.

NATIONAL AID IN IRRIGATION

Few Eastern farmers realise the area of land in the West that is still owned by the United States Government. It amounts to over six hundred millions of acres and is located chiefly in Arizona, California, Colorado, Idaho, Montana, Nebraska, Nevada, New Mexico, North Dakota, Utah, Washington and Wyoming. A large part of this vast area possesses great inherent fertility, which is rendered valueless by the lack of water. As President Roosevelt states it, "In the arid regions it is water, not land, which measures production."

Much of this area is traversed by streams that can be used to reclaim it. But most of the land which can be irrigated by small canals, such as can be built with the combined means of a number of farmers, or a stock company, has already been brought under ditch. These are mostly the river bottoms and low bench lands. These constitute, however, but a small per cent. of the great area of land that it is possible to make productive by irrigation. There are large enterprises that are beyond the reach of private capital. There are millions of acres that may be made as fertile as any land on the continent, and at a comparatively slight cost per acre, if sufficient capital could be found to build the immense reservoirs and canals that this reclamation entails. It cannot be done by the different states, for interstate disputes concerning water rights would arise. It is a National, not a state or private problem. So it has come about that there has been a strong appeal from the West for government aid. This appeal has been heeded.

The Reclamation Act of 1902.—Under this Act the Government purposes to irrigate, and so make productive, a vast area of land now of little or no value. Some authorities estimate the total area which may be benefited by this Act as close to fifty millions of acres, which are located in parts of all the states and territories in the arid and semi-arid regions. This Act provides that all money from the sale of public lands in the arid West shall constitute a special fund to be used in the survey and construction of reservoirs and canals for the reclamation of arid and semi-arid lands.

The U. S. Government has already expended about ten millions of dollars, of thirty-four millions appropriated, in making surveys, constructing reservoirs and digging canals. The reservoirs are built chiefly for the purpose of storing flood water that it may be turned into the streams at low water. Additional money for this work will be derived from the sale to settlers of government lands in these states and territories after it has been brought under ditch. This land is to be divided into farms of not less than 40 or more than 160 acres, which is enough to support a family of five. Only actual settlers can take advantage of the privileges of this Act; there is no room for speculators. Those who settle upon these homesteads are required to repay the government, in ten annual instalments or less, the extent of their indebtedness, which is the proportionate cost of supplying their land with water. The cost of construction is repaid by the sale of the land reclaimed. The money will then be used by the government for developing similar enterprises in other sections.

There are already under construction, or definitely in view, fourteen irrigation projects which, when completed, will water about a million and a half acres of land. These projects are not in a few states, but in all of them; there is a comprehensive scheme for irrigating the entire area of arid land that it is practicable to irrigate. Small systems, called "units," are to be established here and there as may be most expedient, with a view to future additions and development, until a vast area is watered by one great system of reservoirs, rivers and canals.

It was a notable event in the history of American agriculture when the first irrigation system to be opened under the Reclamation Act—the Truckee-Carson Project, in western Nevada—was formally opened on June 17, 1905, in the presence of a large and enthusiastic assemblage. When this single unit is completed it will cost about ninety millions of dollars and will water about three hundred and seventy-five thousand acres in excess of the area now supplied.

In addition to providing irrigation systems, the National Government is endeavouring to aid arid farming by protecting the forests of the West. Most of the streams from which the water is drawn have their origin in forested mountains. Cutting off the forests or allowing them to be burnt off would make the water supply more uncertain. Contrary to the popular notion, forests have but little effect in increasing rainfall, but they have a very marked effect in regulating the flow of streams. Over forty-seven million acres of forests have been set aside for the protection of the headwaters of irrigation streams. President Roosevelt said in his message to Congress, December 3, 1901: "The forests are natural reservoirs. By restraining the streams in flood and replenishing them in drought they make possible the use of water otherwise wasted. Forest conservation is therefore an essential condition to water conservation."

This is a development scheme of stupendous proportions. It is worthy of the genius and enterprise of the American people who, as a people, are now pledged to execute these plans.

Windbreaks.—In the subhumid sections of the central West, particularly eastern North Dakota, eastern South Dakota, central Nebraska, western Kansas, central Oklahoma and central Texas, windbreaks are frequently of great service for protecting the ground from the sweep of dry winds, which evaporate much moisture from the soil, and often blow the lighter soils into drifts. Sometimes crops of grains are literally blown out of the ground after they are 3 to 5 inches high, their roots being uncovered by the blowing away of 2 or 3 inches of soil. Even slight barriers, as fences, lessen the injury from wind for a distance of several hundred feet to leeward. Lombardy poplars, cottonwoods and locusts are commonly used for high windbreaks, and Russian mulberry and the shrubby Artemisia for low hedges. A cottonwood windbreak 40 feet high has a beneficial influence to a distance of 650 feet to the leeward, preventing the soil from drying out rapidly and from drifting.

In the plains states where these conditions prevail, windbreaks should always be provided; they are especially needed in the subhumid sections where irrigation is not possible, and the rainfall is scanty. The plants of a windbreak do steal much moisture from the adjacent land, but in windy sections they save much more than they steal, by keeping drying winds from hugging the ground. Broad fields should be avoided and, if possible, a system of rotation should be adopted that will keep fields in alternate strips of grass or clover and tilled land.

CHAPTER XI

MAINTAINING THE FERTILITY OF THE SOIL

THE greatest problem in farming is that of maintaining the fertility of the soil. The fertility of the soil is its power to produce crops. It is not mere plant food; it is water, air, sunlight, plant food, temperature, soil bacteria, and all the other factors and conditions that make a soil habitable for plants. It is concerned with the texture of the soil as much as with its richness; and its water-moving power as much as its composition. Plant food is but one of many conditions necessary to the growth of crops, and often it is the least essential condition. The fertility of the soil is the sum of all the conditions that make it possible for the seed to sprout, the blade to spread and the ear to ripen. It is the inherent power of the soil to produce crops.

The problem of maintaining or restoring the fertility of farm soils, then, is much broader than that of merely adding plant food to them. When we speak of fertility we naturally think first of manures, fertilisers and other means of enriching the soil. These are very important sources of increased fertility, but fertility is not as dependent upon them as many believe. The way in which a soil is handled has fully as much to do with its fertility as its composition, or the amount of plant food added to it. It depends upon plowing, harrowing, cultivating, rolling, draining, irrigating and all other tillage and cultural operations fully as much as upon manuring, fertilising, fallowing and the like. A really comprehensive discussion of soil fertility should consider all the ways in which a soil is handled or is acted upon by natural forces, as well as means of enriching it, and of conserving native richness. The methods of handling soil and their relation to productivity have been discussed in previous chapters. The remaining chapters will be devoted to the methods of enriching soils and husbanding natural resources.

Many Views.—There are many views, and unavoidably many conflicting views, on this great problem. Some seek to solve it in one way and some in another. Certain men lay most stress on the texture of the soil and the movement of soil water as a measure of the producing power of a soil. Others emphasise thorough tillage above all else. Another says, "Grow clover and plow it under; it is the key to fertility." Others lay stress upon good texture and the addition of humus. We hear something of inoculating the soil to make it fertile. Even now the most commonly accepted views on soil fertility have been challenged by an eminent soil physicist whose conclusions, if accepted, will almost revolutionise our views about the effect of manures and fertilisers on soils. In addition to this honest difference of opinion, there are many quack remedies for preserving or restoring soil fertility. The following pages present the views most commonly accepted at this time.

THE NATIVE RICHNESS OF SOILS

Plant food is not fertility, but it has a very important influence on fertility. A soil's power to produce crops is very rarely measured by the amount of plant food it contains, yet mere richness is a very valuable asset of a farm soil, and no man can afford to disregard it in the modern emphasis on good texture and other desirable attributes.

The actual richness of a soil in plant food depends largely upon its origin and its fineness. A leachy, sandy soil, for example, is not likely to contain more than a third as much plant food as an alluvial clay; a limestone soil is usually richer than a slate soil, and so on.

The Soil a Storehouse of Plant Food.—The point that needs to be emphasised most, however, is not that farm soils vary greatly in native richness, but that practically all farm soils, including those that we consider poor, contain a vast amount of plant food.

The analyses of representative soils in the Appendix show that all of them contain almost unbelievable quantities of the plant foods that we buy and apply so grudgingly. An average farm soil usually contains about 4,000 lbs. of nitrogen, 6,000 lbs. of phosphoric acid, and 20,000 lbs. of potash per acre in the upper eight inches of soil. "Worn-out" soils, which scarcely produce enough to pay for cropping them, often contain nearly as much plant food as this—while some rich soils have over 6,000 lbs. of nitrogen, 10,000 lbs. of phosphoric acid, and 50,000 lbs. of potash per acre in the first eight inches. Besides all this large amount of plant food in the surface soil, the soil below the first eight inches usually contains nearly as much, and a part of this can be used by the roots of most farm crops.

These figures are astounding to those who have believed that a soil gradually ceases to be productive because the plant food in it becomes exhausted.

The chemists give us indisputable proof that even a soil that has become so "poor" that it hardly pays to crop it, is likely to have stored within it tons upon tons of plant food; that it is in no way exhausted, as we have been taught to believe. Yet the fact remains that this same soil will not produce large crops. What, then, is the trouble?

Plant Food Locked Up.—Much of the tons of plant food that the chemist finds in ordinary farm soils, is "locked up", or unavailable, from two causes. In the first place it may not be in the right form for plants to use, it may be in a compound that is distasteful to the plants; or it may be in a form that is not soluble in soil water, so that it cannot be absorbed by the roots. Plants accept food only when it is in a certain form. The chemist, however, cannot tell how much of the total amount of nitrogen, potash and phosphoric acid that he finds in soil is in such shape that plants can use it. He cannot determine with any degree of certainty what proportion of the 4,000 lbs. of nitrogen, 6,000 lbs. of phosphoric acid and 20,000 lbs of potash that are in an acre of average farm soil is in the right form for crops to use. There is no way of finding out this very important point except to grow plants upon the soil.

Poor Texture a Cause of Infertility.—Part of this great amount of plant food that is found in all ordinary farm soils may have been made useless to crops, for the time being, by poor texture, lack of warmth and poor drainage.

Mere richness in plant food avails nothing if there is not enough water to make a very large quantity of a weak solution of that food for the roots to absorb. The arid lands of the West are very rich in plant food, but are valueless for cropping until water is applied to them. In many cases the amount of water in the soil measures its producing power more than the amount of plant food in it. Furthermore, the tons of plant food in a soil are as valueless as sand unless the soil has the power to move water rapidly to meet the needs of the crop.

Under-drainage may make an unproductive, yet rich, soil productive. Plowing under green-manures may effect a similar improvement. These methods are discussed in detail in subsequent chapters. The point to be emphasised is that although most farm soils are very rich in plant food, usually but a small percentage of this can be used by crops, and that tillage, drainage, a rotation of crops and the addition of humus are methods of increasing the usefulness of native plant food.

SOILS EXHAUSTED OF PLANT FOOD

We ordinarily think that a soil becomes exhausted of plant food chiefly by continuous cropping. We see the yields from a soil that produced sixty bushels of corn per acre fifty years ago, when it was virgin, gradually dwindle to twenty-five bushels, with prospects of going lower still. On the face of it, this is due to the exhaustion of the plant food in the soil by the corn crop. But is it? The drain of crops upon the soil's store of plant food is really so slight, when compared with the total amount of plant food in the soil, that it is scarcely worth mentioning as a cause of the increasing unproductiveness of that soil. A crop of cotton of one bale per acre, which is twice the average yield, makes a draft upon the soil of 28 lbs. of nitrogen, 9 lbs. of phosphoric acid, and 13 lbs. of potash each year per acre. A crop of 50 bushels corn per acre removes 96 lbs. of nitrogen, 33 lbs. of phosphoric acid and 68 lbs. of potash each year per acre. A crop of 1½ tons of hay per acre removes 35 lbs. of nitrogen, 7 lbs. of phosphoric acid and 39 lbs. of potash; of wheat, at the average yield of 14 bushels per acre, 33 lbs. of nitrogen, 10 lbs. of phosphoric acid and 17 lbs. of potash.

Compare these small amounts of plant food removed by average crops with the vast amounts that are in ordinary soils. What are they when compared with the 4,000 lbs. of nitrogen, 6,000 lbs. of phosphoric acid and 20,000 lbs. of potash that the upper 8 inches of an average soil contains! In addition to all this is the undeveloped richness of the subsoil, which becomes of use from year to year. The average soil ought to produce bumper crops for hundreds of years without adding any fertiliser, if we considered but two facts—the great amount of plant food in the soil, and the very small amount removed by crops.

But other things must be considered. If only a small part of the 4,000 lbs. of nitrogen, 6,000 lbs. of phosphoric acid and 20,000 lbs. of potash is available to plants—as is usually the case—the drain of the crop upon this amount of *available* plant food may be quite heavy. This is especially true on the light and leachy soils, from which the soluble plant food is quickly lost by leaching. In other words, the amounts of plant food drawn from the soil by farm crops makes little impression upon the total amount that is in it, but it often does make a decided impression upon the amount of soluble or available plant food in the soil, which is, after all, the kind of plant food that is of chief interest to the farmer.

The gradual decrease in yields on soils that have been cropped for many years is occasionally due, in part, to the exhaustion of soluble plant food. Usually it is due, wholly or largely, to the way in which the soil has been handled. It is more apt to be a problem in improving the physical condition of the soil than in enriching it. This fact has been proved on thousands of American farms, where better tillage, more thorough drainage, rotation of crops, green manuring and other methods of improving the texture of a soil have been practised. These matters are discussed at length in other chapters.

LOSS OF FERTILITY BY EROSION

Not all of the plant food that is lost each year from farms is carried off in crops. A far more damaging cause of reduced yields on some farms is erosion, or the washing of soil. This removes the best part of it—the surface soil that has been made fine and has had its plant food made soluble by weathering.

The loss of fertility by erosion is one of the greatest leaks on American farms. The chief reason why erosion is so dangerous is that it is insidious. Its ravages are not very conspicuous until it has done much damage. Erosion does not ruin a soil in a single night, or a single season; it starts from small beginnings, usually unnoticed, and creeps stealthily upon the land. Every tiny rill trickling down the slope carries off some of the finest and richest soil on the farm. After a heavy rain the puddles in the hollows are muddy. The deep furrows left up and down the slope by the cultivator teeth become miniature watercourses, and the trickling water exacts a tribute of rich

85. A BARNYARD IN THE SHENANDOAH VALLEY, VIRGINIA

Probably a hundred dollars' worth of plant food is running to waste from it each year. Such scenes are common all over the country. One way of keeping up the fertility of a farm is to husband its resources

86. THE OHIO RIVER FLOODING ITS MEADOWS

It leaves half an inch of rich mud upon the land, which is commonly used for corn. The fertility of many bottom lands is increased in this way

87. PASTURING WITH CATTLE

This is the best method of keeping the fertility of some lands, especially those that are steep, rocky and inclined to wash

88. SHEEP AT PASTURE

They congregate at night upon the hilltops, which are enriched by their droppings. In western West Virginia, and elsewhere, sheep husbandry is a popular method of enriching hill lands soil before it joins the large rill by the road. The cornfield that was left bare all winter has lost some of its best loam by planting time. Gullies appear on the farm here and there, widening and deepening after every rain. The soil on the knolls and hills becomes thin and yellow, for the rich, black surface soil has been washed into the bottoms, and part of it has hurried off to help build up some excellent farming land down stream.

After a heavy rain the farmer can see the best part of his soil creeping, running, racing away from him. A thousand murky rills slowly meander across his plowed ground, and gather force in the hollows. A hundred turbid rivulets pour down the hollows and join waters in the gulch. A dozen muddy brooklets rush down the gulch, swell the brook into a creek and race down stream, bearing away tons of the rich silt and loam that make plants grow. When the rain is over and the soaked soil has dried out enough to till, there are gravelly places that the farmer finds it hard to make productive, and rocks are exposed.

In extreme cases the soil may be almost or wholly ruined for cropping in a few years, becoming gullied and thin. In most cases, however, the loss is less conspicuous, but scarcely less disastrous. This is an exact report of what is taking place to-day on thousands of American farms.

The Great Loss by Erosion in the South.—Every farm that has an irregularity of surface, however slight, pays tribute to the force of moving water. The most serious losses from erosion, however, are on hill farms. The red clay soils of the South, and especially in the uplands of Tennessee, Georgia, the Carolinas, Mississippi and along the banks of the Ohio River, are gouged and gullied every year, unless properly handled, until they may become almost or quite useless for cropping

W. J. McGee reports: "The destruction is not confined to a single field, or to a single upland, but extends over much of the upland. . . . It is probably within the truth to estimate that 10 per cent. of upland Mississippi has been so far converted into bad lands as to be practically ruined for agriculture under existing commercial conditions, and that the annual loss in real estate exceeds the revenue from all sources; and all this havoc has been wrought within a quarter century." This is an extreme case, but it illustrates what is taking place, in a lesser degree, in many other parts of the South.

We have thousands of square miles of lands that are rapidly approaching desolation by erosion. Over a large area the work of destruction has already gone so far as to make it impracticable to try to save the land for cropping. The problem of erosion is most serious on the hill farms of the South; but hill lands in California, eastern Oregon, Washington, and Montana, have been grazed so close that the soil has been exposed, gullies have appeared, and the lands are now nearly worthless. Erosion is also serious on sloping lands in all other parts of the country.

METHODS OF CHECKING EROSION

The method that will be most practicable depends upon the locality, the contour of the land, the nature of the soil, the crop and other local matters.

Preserve Forests and Wooded Strips.—In extreme cases it is necessary to retain wooded areas running across the slopes that are subject to washing.

If the land is hilly and will probably wash badly if cleared, the less of it that is cleared, the better. We rarely find bad gullies in woodlands, even on the steepest hillsides; the roots of trees hold the soil and the humus beneath them absorbs and holds the water, preventing it from gathering in channels. Moreover, much of the rainfall does not reach the soil, being intercepted by the foliage and evaporated before it reaches the ground. The direct force of the rain is also broken. It may be wiser to farm only the bottom land and gentle slopes, and cultivate them more intensely, than to clear uplands that are bound to wash badly after most of the humus in them is destroyed by cropping.

If it is necessary to clear long slopes much may be done to prevent serious loss from erosion by alternating strips of forest with strips of tilled or pasture land. The retaining strips of forest should be twenty or more rods wide, depending upon the steepness of the slope, and should run diagonally across the slope or follow the contour of it. It is especially necessary to keep the tops of hills in forest, because there is where the water begins to collect; moreover, the soil of hill-tops is apt to be thinner and poorer than soil lower down the slope.

Slopes that have already been cleared and have started to wash badly may have strips of woods planted across them. In a surprisingly short time trees will make an effective barrier to erosion. It may be wise to give up an entire slope that is washing badly to forest growth. Native trees usually come in quickly, but if they do not seeds or seedlings may be planted.

Planting Trees to Prevent Erosion. — When planting forest trees to prevent or check erosion, if the land is not too rough or stony, it is best first to plow the land deeply. Most tree seeds are benefited by partial shade the first year and may be sown with a field crop, as peas, oats, or other grain. These seeds may be of such quick-growing trees as white maple, loblolly pine, elm, green and white-ash, and black locust. The seeds should be gathered as soon as ripe and sown immediately. From three to five bushels of the winged seeds should be sown, and others in proportion according to size. It is best to sow each kind separately and thickly enough to secure a dense stand. The quick-growing trees, as elm, soft maple, and ash, are not as valuable for timber as hardwood trees. Black locust and loblolly pine are among the most useful trees for this purpose. *Catalpa speciosa* and chestnut may also be used to advantage.

Transplanting seedlings is more expensive than seeding and the results are more or less uncertain, so it should be done only when seeding is impracticable. Soft-wooded sorts, as the poplars, box elder, also the catalpa, are most commonly propagated by cuttings. The cuttings should be 13 to 16 inches long, of two- or three-year-old wood, and should be taken in late winter. The lower ends are laid in water until planting. They are planted most rapidly with a dibble and so deep that only two or three buds are above ground.

If trees for transplanting are to be grown from seed make beds 3 to 4 feet wide in a rich mellow soil; cover the seeds lightly, and mulch with forest leaves until they have germinated. Shade the beds by piling brush and boughs upon them, or by building lath roofs over them, an open space the width of a lath being left between laths. The seedlings are ready to transplant when two to four years old. In many cases it may only be necessary to dig wild seedlings. Seedlings two to four years old are often found in great numbers on the outskirts of woodland. Set all plants, whether seedlings or cuttings, not more than three feet apart each way, giving 5,000 to 7,000 per acre. In some cases it may be well to make a first planting of the quick-growing softwood trees, and plant the hardwood trees later.

Directing Water.—Much may be done to check erosion by directing the water into legitimate channels, instead of allowing it to meander over the fields, making channels that broaden and deepen with each rain. Careful farmers spend considerable time in their fields during and after heavy rains, guiding, checking, and diverting the rivulets. In most fields there are a number of depressions, or natural water courses, that should be kept free of obstructions.

Terracing.—One of the most common endeavours to check erosion in the South is by terracing. Much of the farm land in Georgia, Alabama and the Carolinas is terraced. The slope is laid off into a series of checks which follow the contour, giving a series of nearly perfectly level steps upon which water may remain and be absorbed. The width of these varies from 50 to 300 feet. The banks of the terrace are usually sodded or seeded with grass. The land between the banks is brought to an approximate level, sometimes by scraping but more commonly by moving it down hill gradually with a reversible plow; it often requires several years to bring the surface into a level condition.

Side-hill Ditches.—Another method is to build side-hill ditches, which follow the contour and have a fall of 1 to 5 inches in 100 feet. They are 6 to 10 feet apart on a very steep slope and 15 to 30 feet apart on a gentle slope. The ditches are made mostly with a plow. They should be sodded with grass. There should be no low places where the water will collect and break through. Unless built with great care they are apt to scour or break.

Terraces and side-hill ditches are not used now as much as formerly. They prevent washing in many cases, but they occupy land that ought to be in crops and they breed weeds. The land is cut up into small fields, increasing the cost of production. In many cases terraced or ditched hillsides wash badly. Deep plowing and green-manuring are usually more serviceable than terracing for preventing these soils from washing, and all the land can be cropped.

Holding the Land With Soil-binding Plants.—This is the most practicable solution in many cases, especially on gentle slopes. If erosion has not progressed so far that the land will not grow a thick turf, the slope may often be made into a pasture or meadow with gratifying results. Grass roots hold the soil tenaciously and the stubble divides surface water and prevents it from accumulating. But it is often difficult to get a close turf established.

Grasses with creeping root-stalks, like Bermuda grass, are most valuable for this purpose. Bermuda grass is the salvation of many Southern hillsides. It makes a very dense turf in a remarkably short time. Sometimes it is established in this way: Shallow furrows are plowed diagonally across the slope, 4 to 6 feet apart. Small pieces of Bermuda grass are dropped in the furrows, 2 to 3 feet apart, and covered. Bermuda grass spreads with great rapidity by means of its underground stems. In two years it has filled the furrow and the field is then plowed diagonally across the furrows. This distributes the grass and it soon takes complete possession of the land, effectually preventing further washing. Bermuda grass makes excellent hay and pasturage.

Other grasses besides Bermuda have distinct merit as soil binders. In the North the Hungarian brome grass is especially valuable for this purpose. The little Lespedeza, or Japanese clover, that comes naturally into cleared ground and pastures in many parts of the South, is a useful soil-binder, and valuable for pasturage. It is moreover, a leguminous plant and enriches the soil. The increasing use of cover crops shows the growing appreciation of the loss by erosion on bare lands during the winter and early spring. Rye or crimson clover, sown at the last cultivation of corn, covers the field with a mat of herbage during the winter, effectively preventing serious washing of the soil. Other benefits of cover crops are considered in the following chapter.

Breaks.—Any material used to check small gullies is called a "break," in the South. Corn stalks, cotton stems, brush and inferior hay are commonly used for this purpose. The material is usually laid lengthwise of the gully, making a dam, which should be wide enough and high enough to back up the water and deposit the soil it contains. If the gully is large it may be necessary to hold down the brush with logs or poles, the ends of which are firmly fastened into the sides of the gully and braced with stones; if small, a few forkfuls of stalks or brush may answer. Willow, poplar, or alder are preferred for making a brush break on uncultivated land because they often sprout, take root and then permanently hold the soil.

Breaks are almost indispensable to good farming in many parts of the South and ought to be used more on the upland farms of other parts of the country. The practice of searching for gullies and checking them with breaks should be as much a part of farm routine as plowing and seeding. Careful farmers go over all their cultivated land several times a year and check gullies. A gully that can be stopped with a forkful of brush to-day may need half a wagon load if left a year. It must be remembered, however, that breaks are a temporary expedient. The real trouble is the inability of the soil to absorb much water rapidly. Deep plowing, green manuring or sodding may effect a permanent improvement.

Increasing the Water-holding Capacity of the Soil.—The more readily a soil absorbs water, the more it can hold without running over as surface drainage, and hence the less likely is it to be injured by erosion. The soils most commonly subject to gullying are clays. These absorb water very slowly, so that during a heavy rain a very large percentage of the water is not absorbed by the soil—even though the soil is quite dry—but flows off as surface drainage, causing erosion. One of the most practicable ways of checking erosion is to increase the water-holding capacity of the soil by under-drainage, by adding humus and by deep plowing. The soils that are most commonly subject to erosion, however, it is not usually practicable to underdrain; the addition of humus and deep plowing are more serviceable. Plowing under green-manuring crops makes these gullying clay soils lighter and more porous, so that they absorb more water, and absorb it much faster.

Deep plowing increases the depth of the soil that can hold film water, so that less runs off on top. Shallow plowing makes the soil reservoir shallow, so that rains quickly fill it, spill over it, and run down the surface. The one-negro-one mule-one-shallow-working-plow combination is responsible for much of the washing of Southern hill farms. Land has been plowed for years not over four or five inches deep, when it ought to be plowed not less than eight inches deep.

Tillage Operations Affecting Erosion.—The simple precaution of running the rows of crops across the slope, not up and down it, so that the cultivation furrows may not be in a line with gravity, will do much to prevent erosion. The furrows become watercourses during very heavy rain. The loss in this way is especially serious if the furrows are left running up and down slopes during the winter. Every upland farmer is familiar with the triangular patches of fine soil at the lower ends of these furrows in the spring. The aggregate loss in this way may be very great. The rows of crops should be kept as nearly on a level as possible, even though this necessitates many windings. We are often told that straight rows look business-like, and crooked rows slovenly. That is true for the prairie farmer but not for the upland farmer.

Broad-tooth cultivators leave the soil in deep furrows and high ridges, and so assist erosion. The broad "sweep" and plow-like cultivators so commonly used for "laying by" cotton and corn are the worst offenders. Sweeps do excellent service in cutting off weeds, but they leave the soil much ridged and furrowed, the beginnings of gullies. Tools of this character are often indispensable, but the furrows they make should be levelled off with a shallow-working implement, as a spike-tooth cultivator.

The practice of ridging corn, potatoes, cotton, and other crops is responsible for much gullying. Unless ridging is made necessary by poor drainage, it is rarely a profitable practice. Deep plowing and deep planting may accomplish the same result, with less danger. Level culture should be practised wherever erosion is likely to be serious.

The somewhat detailed attention given to erosion in this chapter is not out of proportion to its importance in the farm economy of this country. Erosion is stealing from many farms the fertility that should have been bequeathed to posterity. There should be an increasing concern among farmers about this phase of soil fertility.

FALLOWING AND SOIL FERTILITY

Fallowing—leaving land uncropped for one or more seasons—was a common farm practice up to the beginning of the last century. The Mosaic law commanded that land should be fallowed one year in seven. At present it is rarely practised in America, except in the arid regions, although still quite popular in many parts of Europe. The chief reason for this is the rapid improvement of tillage tools. The crude tillage tools of earlier years pulverised the soil so imperfectly, that the increase in available plant food by weathering was very slow; hence crops quickly exhausted the soil. It was soon noticed that if land was cultivated while it was being rested it would be more productive thereafter. The chief advantage of the old-time fallowing was that it promoted weathering and so increased the amount of soluble plant food in the few inches of surface soil that were stirred by the clumsy tools of that time. Modern tillage tools prepare the soil so thoroughly and deeply that a larger area is laid under tribute, and weathering, and other agencies that increase fertility, have a better opportunity to work. There are still occasions, however, when fallowing is beneficial and sometimes very essential.

Fallowing to Store Water.—The value of fallowing in American farming is chiefly in storing water in the soil and cleaning the land of weeds, rather than in increasing the amount of soluble plant food in the soil. In the semi-arid and arid sections of the West where "dry farming" is practised, fallowing is often indispensable. The land is cropped one year and fallowed the next, or it is fallowed one year in three. Fallowed land is plowed and harrowed so that the soil will receive and hold all the rainfall. Where the rainfall is less than ten to fifteen inches such a proceeding may be absolutely necessary. King found that the fallowed part of a certain field contained 203 tons more water per acre in the spring succeeding the fallow than the part that was not fallowed. Even at the end of the season, after large crops of grain had been taken from the land, it contained 179 tons of water more than the unfallowed land. This shows that summer fallowing has a marked and lasting influence on the moisture content of soils. It is likely that fallowing to store water will always be practised in America far more than fallowing for any other specific purpose.

Fallowing to Set Free Plant Food.—Fallowing increases the amount of available plant food in the soil, especially nitrogen. The soil of the fallow field is stirred frequently and is warm and moist, conditions that are favourable to making inert plant food soluble. This plant food is stored for the crop of another year unless the soil is leachy, in which case much of the quickly soluble nitrogen may be lost. This is the chief disadvantage of fallowing on certain soils. It is doubtful if it is ever wise to fallow land chiefly for the purpose of increasing its supply of available plant food. Usually the same result can be secured, without losing the use of the land, by a rotation of crops and better tillage.

Fallowing may be used to advantage in some cases for cleaning land of weeds, especially the weeds that gain a foothold in grain farming. Bare summer fallowing is an excellent means of getting rid of both perennial and annual weeds, especially the Canadian thistle. But if summer-fallowed land is not kept harrowed, fallowing may increase weediness.

The Methods of Fallowing.—Land that is to be fallowed should be plowed early and at once fitted thoroughly. Most of the weeds will immediately start to grow; these may then be killed by plowing again or by harrowing. In some sections fallow land is plowed three times during the season. Such a mixing and interchanging of particles cannot help but make a soil more fertile, as well as increase its moisture content and improve its texture. In some cases one plowing and one to three harrowings, at intervals during the summer, may be about as effective as three plowings. The important point is to keep noxious weeds from starting; some fallows are allowed to become foul with weeds. If the fallow is to be followed by rye or wheat, the last plowing is usually given before the middle of August, so that the soil may have time to settle and become compact before seeding.

Oftentimes a short fallow may be practicable. This consists simply in tilling the soil during the few weeks that may elapse between the harvesting of one crop, as barley, clover, or oats, and the sowing of the next crop, as wheat. Occasionally land is left idle for several weeks, or longer, when it ought to be at work, either growing a green-manure to plow under, or being subjected to the weathering that is set in motion by tillage.

Summary of Value of Fallowing.—In American farm practice, fallowing is used to advantage chiefly for increasing the water content of soils, and for cleansing them of weeds, rather than for increasing their supply of available plant food and improving their texture. It is often practicable in the dry sections but rarely in the humid sections. It is not adapted to leachy soils. In this country fallowing is practised chiefly in the arid and semi-arid regions, under dry farming, and mostly in the culture of wheat and oats.

ROTATION OF CROPS

Rotation of crops is the order or system in which crops are grown upon the same land, and refers to the sequence of crops when a number of different kinds are grown, in distinction from the one crop system.

Very early in the history of agriculture it was noticed that many crops grew much better if they followed some other crops than if grown continuously on the same land. Centuries ago English farmers divided their land into three parts, one part being in spring-sown grain, another in fall-sown grain, the other third being summer-fallowed. In more recent years farmers have noticed that it not only benefits some crops to follow different crops, but also that it often makes a decided difference what crops are associated in the rotation.

The practice of growing different crops in succession, instead of one crop continuously, did not originate with man. Crop rotation is almost universal in Nature. The oak forest is cut off and soon the land is shadowed with pines. The pines grow lusty, fall before the woodman's ax, and oaks or white birches take their place. The low-bush blueberry and the arbutus flourish in the hardwood clearings. Everywhere we may see that Nature rarely follows one of her crops with another of the same kind of plant. The wise economy of her rotations we may study with profit.

WHY A ROTATION IS BENEFICIAL

A rotation is usually beneficial in several ways; sometimes one benefit is most pronounced, sometimes another. The explanation that one naturally thinks of first is that it affects the relative supply of the different plant foods in the soil. Every farmer knows that some crops are "harder upon the soil" than others. The chemist, also, says that some plants use more plant food than others. Different crops take from the soil, not different kinds of plant food, as some suppose, but different amounts of the same plant foods. Thus wheat needs more phosphoric acid and less potash than fruits. Oats require more potash than corn. Cropping a soil continuously with corn, for example, is likely to exhaust it sooner of the available plant food that corn needs than if clover, wheat and potatoes are grown in a rotation with corn. The producing power of a soil is measured by the amount of the essential plant food it contains which is least abundant; if it contains 20,000 lbs. of potash and only 2,000 lbs. of phosphoric acid, it can produce no larger crops than the supply of available phosphoric acid is sufficient to nourish. A rotation of crops, if it is well planned, does not subject the soil to a continuous drain of plant foods in the same proportions; it changes the proportions and so makes the plant food in the soil go farther.

The Different Rooting Habits of Crops.—Another reason why a rotation of crops is easier on a soil than single-crop farming results from the different rooting habits of plants. Timothy or blue grass, for example, are shallow-rooting; they draw most of their nourishment from the upper six inches of soil. Clover and alfalfa are deep-rooting; their long tap roots penetrate many feet deep in all ordinary soils, gathering a large amount of food below the depth to which the roots of timothy and blue grass penetrate. The roots of corn forage deeper than the roots of oats. Mangels, sugar-beets and parsnips root deeper than round turnips and table beets, and so on with other farm crops.

The relation of this fact to soil fertility is the advantage to the soil of having crops grown upon it that root at different depths. A soil may be almost exhausted of available plant food for shallow-rooting crops yet contain much for deep-rooting crops. The fertility of the soil is thus conserved by rotating crops that not only differ in their demands upon the soil but also in the relative area of soil that they place under tribute.

A third advantage of rotating crops, in its relation to soil fertility, is the opportunity provided for improving the texture of the soil. When crops are harvested the roots and stubble are plowed under, and since crops vary in the amount of herbage returned, and the depth and extent of the root system, there is greater likelihood that all parts will be benefited by the humus resulting from the decay of roots if several crops are grown. Furthermore, a rotation permits the use of cover crops, catch crops, and other means of improving texture, as discussed in Chapter XII.

Rotation of Crops and Weediness.—Certain weeds go with a certain crop; they seem to find a niche in its cultivation that just fits their needs. Thus we have quack grass in the asparagus bed, purslane in the onions and Canada thistles in the wheat. Furthermore, some crops can be kept free from weeds much easier than others. Note how much faster weeds multiply when sown crops are grown, as rye, oats or wheat, than when crops that are inter-tilled are grown, as corn and potatoes. In this country, weeds cause the greatest loss in the grain fields of the West, where continuous cropping, with or without summer fallow, is practised. Wherever the single-crop system is dominant, weeds become a serious nuisance.

A specific instance where a rotation of crops may be used for cleaning land of weeds will call attention to the usefulness of the practice. Wild carrot and plantain are very troublesome weeds in some localities, especially in the Northeastern States. These plants do not produce seeds until mid-summer. If a two-year rotation of wheat or rye and clover is practised these weeds may be almost completely exterminated, for as soon as the clover is cut they immediately throw up their flower stalks. These may be mowed a few weeks after the clover is removed, but a better way is to plow the clover stubble soon after the first cutting, in preparation for winter wheat or rye.

The value of a rotation of crops for killing weeds depends largely upon the fact that different crops receive different kinds of tillage. Different tools are used. Weeds that escape destruction under the system of tillage given one crop are caught by the tillage of another. Sown crops, especially grains, should be rotated with tilled crops. Grains cover the ground sparsely and there is no inter-tillage, so weeds like the "paint-brush," Canada thistle, dock, and Russian thistle, find an excellent opportunity to gain a foothold. Some crops that grow very rapidly and quickly shade the ground, as potatoes, are not as apt to be weedy as slow-growing and sparse-foliage crops. This should be remembered when planning a rotation.

Insect and Disease Injury Lessened by Rotation.— Each crop has its own peculiar troubles. Some of these are fungous diseases. These are spread mostly by seed-like bodies called spores; each disease has a different kind of spore, which can cause the disease only upon a certain crop. Thus the spore of potato scab can make scab on potatoes, but no other disease, either on potatoes or any other plant. The longer a certain kind of crop is grown upon the same piece of land the more the land becomes infected with parts of diseased plants and with spores, and the greater is the likelihood that the crop will be injured by the disease. This is particularly true of such common diseases as potato scab, and the club root of cabbages and turnips, which increase very rapidly on crops grown for several years on the same soil. It is less true of corn smut, onion smut, and ergot, which increase slowly. A change of crops deprives these fungous diseases of the only kind of plants upon which they can feed, so they disappear. Moreover, crops are less vigorous when grown continuously upon the same land, and are therefore more susceptible to disease.

A number of important insect pests of farm crops may be controlled to a greater or less extent by crop rotation. In general, each crop has its own pests, although insects often feed on more than one kind of plant. Meadows kept for a long time in grass are likely to become infested with the larvae of the May beetle, and with wire worms. A rotation will prevent this.

Keep the Soil Busy.—If but one crop is grown, the soil is usually left bare during part of the year. This is poor farming, except when the land is purposely fallowed. No ground should be allowed to remain idle when it might be growing crops, either to sell or to turn under. The busier a soil is kept, provided the right kind of crops are grown, and provision is made for green-manuring, the more productive it should be. This is more true of Eastern than of Western farming. As land becomes dearer, it becomes increasingly important to keep it busy all the season by means of a well-considered rotation.

Aside from maintaining or increasing the fertility of the soil, a rotation may economise labour. It distributes the labour throughout the year, since crops differ in the time when they are sown and the time it takes to bring them to maturity. This more continuous employment may be exceedingly advantageous, enabling the farmer to secure cheaper and better help, and to give his stock a greater variety of foods. There is, furthermore, a considerable advantage in having the money for crops coming in at different seasons of the year. It is better for the average man to have $3,000 in instalments during the year than $4,000 in a lump.

The extent to which crop rotation is practised is a reliable index to the development of the agriculture of a region. As farming becomes more intensive, specialised and refined, rotations increase. In some of the Western States a systematic rotation of crops is now almost unknown.

CHOOSING CROPS FOR A ROTATION

One could plan an ideal rotation, so far as maintaining the fertility of the soil is concerned, which it would be utter folly to put into operation because of economic conditions—the demands of the market, the amount of help available, and similar factors. Few rotations meet all the requirements, both of the soil and of farm economy. It is usually a question of adopting the rotation that gives the most gain and the least loss; so the planning of a rotation is largely a local and personal matter. There are, however, some general principles that ought to be considered.

1. A rotation should contain as many years as is practicable of the crop that pays the greatest profit per acre. The "money crop" should dictate the rotation. The less profitable crops should be subservient to the money crop, and should make the soil congenial to it. If cotton is the money crop, and the soil is well adapted for growing it, build the rotation around cotton and let the other crops bolster it up. If hay is the money crop, and the

soil makes a strong meadow, keep the land in hay up to the point where the soil would be injured and the yield reduced by retaining it longer in sod. If corn is the money crop, grow corn to the limit of the soil's patience and rotate it with other crops that are most serviceable in maintaining the fertility of a first-class corn field. Maximum profit is the main point to observe in planning a rotation, bearing in mind that no crop is profitable if it is secured by robbing and impoverishing the soil.

2. A rotation should preferably contain at least one crop that improves the soil. This "green crop" may be grown specifically for a green-manure, as a catch crop of rye after corn; or a crop which is harvested, but which nevertheless improves the soil by its growth, as clover or cow-peas. The improvement may be in texture, by plowing under humus; or it may be in actual enrichment, by growing a leguminous crop, as is considered in the next chapter. If it is at all expedient, a leguminous crop should be included in the rotation.

3. If possible, the rotation should include crops that feed at different depths, and that are dissimilar in habits of growth. Deep-rooting crops should alternate with shallow-rooting ones.

4. If the money crop is sown, the rotation should include a "cleanser," a crop that is cultivated, so that the land may be kept free from weeds. In Europe, roots, as turnips, potatoes and swedes, are commonly used as a cleanser; in this country corn and potatoes are most largely grown for this purpose.

Reducing these suggestions to a simple form, a rotation ought to contain a money crop, a manurial crop and a cleansing crop, and give as wide variation in habit of growth and food requirements as is practicable. This general rule is necessarily subject to many exceptions. Sometimes the whole scheme may be upset by economic exigencies, as the relative value of the different crops, the immediate need of the farmer of money, fluctuation in the price of live-stock feeds, etc.

TYPICAL SYSTEMS OF ROTATION

The number of years that a rotation may last varies from two to eight or even more. "Four course" rotations, lasting four years and including four crops, are most common. As a rule, the poorer the land, the shorter the rotation. Fixed rotations are not as common in the United States as in Great Britain. Many good farmers habitually change crops upon their land with quite satisfactory results, without following any definite system. The only sort of rotation followed by many farmers is to alternate a grain crop with a green crop, and a cultivated crop with an uncultivated crop. As this embodies two of the most important principles in crop rotation, one will not go far wrong in following these simple rules, even though specific crops are not assigned in the rotation. Any number of exigencies may arise that may make it desirable to modify or depart from a system of crop rotation; but it is well to have some definite system in mind and follow it as closely as possible.

A few examples of common systems of rotation in the United States will show how the principles outlined above are applied.

1. Potatoes, winter wheat, clover.

This rotation is frequently used when the money crop is potatoes. Nothing is more favourable for potatoes than to turn under a clover sod before planting. The clover is sown with the wheat or is seeded in the growing wheat in early spring. It is the manurial crop of the rotation and potatoes is the cleansing crop. This can be made a two-year rotation by plowing under the clover in early spring, in time to plant potatoes, not allowing it to mature a crop. Rye may be substituted for wheat and sweet potatoes or tomatoes for potatoes, without lessening the value of the rotation. This rotation may be secured with but one plowing. Plow the sod in either fall or spring, plant the potatoes early and use a harrow to prepare the seed bed for wheat after the potatoes are harvested. This can be made a four-course rotation by seeding with clover and mixed grasses; then it becomes an excellent rotation for the dairyman.

2. Corn, oats, wheat, grass and clover.

This is a favourite in the "Corn Belt." It is economical of labour, but is open to serious objection in two respects—when wheat follows oats it is not possible to prepare the seed bed for wheat properly; and two uncultivated crops of about the same feeding habits are together. It is customary to manure the corn; if commercial fertilisers are used, they are applied to the wheat.

3. Corn, wheat, oats.

Where corn is the leading crop this is, in some respects, a better rotation. The chief criticism of it is that one must wait until the corn is ready to harvest before seeding to wheat, which may be so late that the wheat does not make enough growth to stand the winter. Wherever it is practicable to grow potatoes an even better corn rotation is:

4. Corn, potatoes, wheat, clover.

The clover sod is manured heavily before being planted to corn. This is an almost ideal rotation, since the crops of cereals alternate with a root or clover crop. Under certain conditions the crop of wheat may be dispensed with, making:

5. Corn, potatoes, clover.

In this and similar rotations the second crop of clover should not be cut, but should be plowed under to enrich the soil and feed the corn.

The essential point in rotations for stock farming is to provide the maximum amount of roughage and succulence. One of the most useful rotations for this purpose is:

6. Turnips, barley, mixed grasses and clover, wheat.

This is the noted "Norfolk system" used extensively in England. If it is not desired to introduce grain so frequently, this can be made a six-course rotation by cutting the grass and clover meadow three years, thus keeping one-half the farm in hay. This rotation may be modified in many ways to meet varying conditions, as by substituting oats for barley, rye for wheat, mangels or sugar beets for turnips. In this rotation the cereals are separated by roots, which is the cleansing crop, and clover, which is the manurial crop. It is one of the most perfect rotations in existence.

A popular dairy-farm rotation is:

7. Potatoes, one year; corn, two years; grass and clover, three years.

The corn may be put into the silo the second year. The grass and clover mixture is sown when the corn is cultivated last. If desirable, one year of corn or one of meadow may be omitted. The main object in a dairy rotation is to secure a continuous supply of food. The necessity for accomplishing this may make it necessary to adopt rotations that are not ideal, so far as maintaining the fertility of the farm soil is concerned. The abundance of manure may offset this disadvantage.

When either the small grains or hay are the specialties a common rotation is:

8. Wheat or rye; clover, or clover and mixed grasses, three to six years.

In the "Cotton Belt" one of the most successful rotations is:

9. Cotton, rye or clover, corn.

Catch crops of cowpeas are used between these crops. In addition to main-crop rotation, catch crops and cover crops are used in diverse ways.

The foregoing are but a few of many rotations in common use on American farms. In the Appendix is a list of the rotations commonly practised or recommended in each of the states. These lists have been prepared by authorities on the subject and are a record of the best current practice in crop rotation.

SINGLE-CROP FARMING

It must not be inferred that it will never pay to grow a crop continuously on the same land. Often this is the only feasible course—as in some Western grain farming; and again it may be best for certain crops, as onions and tobacco. A summer fallow may be introduced instead of another crop. There are numerous instances of wheat and corn being grown continuously, with little diminution of soil fertility. In the noted experiments of Laws and Gilbert, in England, wheat has been grown continuously on the same land for over sixty years, yet the yields for recent years are much above the average. These are scattered exceptions. The evidence is overwhelming that, in general, the single-crop system, if continued very long, means ruin.

Mention should be made of "succession cropping," as practised by market gardeners especially. By setting out plants from hotbeds, by interplanting and by very high culture, they are able to take three or four different crops from the same land in a single season. The value of the crops removed in one year by skilled market gardeners often reaches astonishing figures. One Massachusetts gardener is reported to have secured a net profit of $2,000 an acre, in 1906. The chief aim of the market gardener is to keep the land busy all the time. He depends little upon the natural fertility of the soil, but mostly upon the very large amounts of manures and fertilisers that he uses, so his rotation is chosen for its economic advantages, rather than for the maintenance of fertility.

SELLING FERTILITY

The maintenance of fertility is a larger and broader problem than how to utilise home resources to advantage, and how to buy fertilisers economically. The farmer should ask himself, "How much fertility am I selling from my farm each year?" The soil is a great bin of plant food from which we draw a small supply each year. It is not like a bin of wheat—to be drawn on each year until exhausted, because it is constantly receiving new food from the decay of plants, weathering of stones and other sources. But cropping does impoverish farm soils of available plant food, reducing their value for cropping, temporarily at least. This plant food is being shipped off in butter, eggs, hay, corn, apples, wheat, cotton, potatoes, and in every other crop that goes to market. The fertility that goes off in crops never returns to that land. But some crops, or part of them, stay on the farm. These are the crops that are fed to stock and the manure returned to the land.

A Bank Account with the Soil.—In reality, when we sell crops we are selling the fertility of the soil, not only the nitrogen, potash and phosphoric acid the crops have used, but also a certain amount of good texture or "condition" which is lost by the growth of the crop. A farmer should know the relation between the price received for his crop and the amount of plant food contained in it.

The amount of fertility lost to the farm by the sale of different crops varies greatly. The loss in grass and cereal crops is much greater than in vegetable and fruit crops. If a ton of wheat, which contains 38 lbs. of nitrogen, 19 lbs. of phosphoric acid and 13 lbs. of potash, sells for 60 cents a bushel, the nitrogen in it sells for 41 cents a lb., and the phosphoric acid and potash for 14 cents a lb. If a ton of milk, which contains 12 lbs, of nitrogen, 4½ lbs. of potash and 3½ lbs. of phosphoric acid, is sold for $30, the nitrogen in it brings $2 per lb., and the phosphoric acid and potash about 70 cents per lb. If, however, cream or butter is sold and the skim milk fed to hogs, calves or chickens, most of the plant food is recovered in the manure of these animals.

Hay is one of the most exhausting crops. If it is sold, practically the entire crop leaves the farm, carrying from it large quantities of plant food, which is sold at a very low price per pound. When a crop that contains a large amount of plant food, as hay, sells for a low price, it is usually best to sell it not as hay, but as a manufactured product—as milk or butter, for example. The farmer ought to think of the several thousand pounds each of nitrogen, potash and phosphoric acid that his soil probably contains, as so much capital stock. He draws a cheque upon his soil bank every time he removes a crop from it. He should see to it that every pound of plant food that leaves the farm as raw material—like grain, hay, potatoes, or as manufactured products—as milk, butter, beef, pork, eggs, wool, brings him a profitable income.

On investigation the farmer may find that he is selling plant food at a ruinous price. Then there are two alternatives: to grow other crops which contain less fertility and sell higher per pound of plant food contained; or to sell the crops as manufactured rather than as raw material. This enforces the necessity of introducing stock of some kind to manufacture the crop into products like butter, eggs, or pork, which, when sold, do not diminish the farm fertility bank account to any appreciable extent. Then begins diversified farming, of which stock husbandry is the backbone.

The Minnesota Agricultural Experiment Station has published the results of experiments on the loss of fertility under different systems of farming. The gain of nitrogen from growing clover is not considered in the following figures:

APPROXIMATE LOSS OF PLANT FOOD IN ONE YEAR FROM 160 ACRES OF LAND UNDER DIFFERENT SYSTEMS OF FARMING

System of Farming	Phosphoric Acid Pounds	Potash Pounds	Nitrogen Pounds
All grain	2,460	4,020	5,600
Mixed grain and general	1,003	1,047	2,594
Mixed potato and general	991	2,435	2,363
Stock	35	59	898
Dairy	76	85	809

Commenting on these results the report says, "With stock farming, when all the crops are fed to the stock on the farm and a small amount of milled products is purchased, there is practically no loss of potash and phosphoric acid except in handling the manure. When the manure is well cared for the loss of these plant foods is less than is stated. When all the skim milk is fed on the farm and a part of the grain exchanged for more concentrated mill products, there is no loss but a constant gain of fertility."

These figures are, of course, only approximate and subject to much variation; but they show where the heaviest drafts fall on the soil under different systems of farming.

The type of farming followed, whether stock, fruit, grain, hay or otherwise, is usually determined by economic conditions that are of far greater importance than the question of maintaining soil fertility. A farmer grows the crop or rears the stock that he thinks will be most profitable in his situation as regards soil, climate, market and similar factors. He is more concerned about growing crops that pay this year and next, than about handing down to his son a farm on which the soil has not been seriously impaired in fertility. But the larger consideration of maintaining soil fertility for other generations surely deserves serious thought from the farmer of to-day. In any case it is likely that he will have the subject brought to his attention by self interest. The effects of pursuing a system of farming that continually takes from the land and returns nothing or little to it may be seen within a generation, or even within a decade. Each year thousands of American farmers are radically modifying their systems of husbandry for the purpose of maintaining the fertility of their farms. Sometimes this must be done, apparently, at the expense of self interest, at least for a few years. Some of the crops that have paid best either must not be grown at all or grown less frequently. But a series of years may tell another story.

DIVERSIFIED FARMING

The number and kinds of crops grown are largely determined by the distance to the market. Eastern farmers, who are close to large markets, grow a greater variety of crops than Western farmers. Cotton in the South, corn in the Central States and small grains in the West are the most conspicuous examples of single-crop farming in the United States. There are many small single-crop areas, as Aroostook County, Maine, which is devoted largely to the culture of potatoes. Single-crop farming does not necessarily mean that but one crop is grown; it may mean that one main crop is grown with a few secondary crops. Small grain farming, even though wheat, oats, and barley are grown, would be considered, in its effect on soil fertility, as single-crop farming.

The chief disadvantages of a too rigid adherence to single-crop farming are the unequal distribution through the year of labour and of returns, and the certain exhaustion of the soil sooner or later, by almost continuous cropping with one plant or closely related plants. Single-crop farming, if persisted in, means ruin. Diversified farming is one of the strongest props of soil fertility. Undoubtedly the farming in some sections of the country, especially the far West, must be single-crop, or practically so, in order to be profitable, for the farmer must grow what he can sell at a profit. But other crops should be introduced whenever possible. It is very hard to persuade the farmer who has been growing corn, or wheat, or cotton, and little else, that it will be for his interest to diversify his farming. These have been his money-making crops. Yet the time always comes when he is forced, by the lessening fertility of his soil, to introduce "green crops," to feed more stock, and to rest his overworked land.

KEEPING LIVE-STOCK TO MAINTAIN FERTILITY

Theoretically, the most economical way of maintaining the fertility of the soil is by growing crops to feed live-stock and returning their excretions to the soil; practically, this is the most enduring method. If all the conditions for caring for and applying manures were perfect, from 70 to 90 per cent. of the plant food in what the animals eat would be returned to the soil in the manure and urine. Practically a much smaller per cent. than this is recovered, for there is always loss in storing and handling manure. But even granting that the percentage of plant food that can be recovered in manure is considerably less than is commonly stated, the keeping of live-stock remains one of the most economical methods of maintaining soil fertility under certain conditions. These are largely economic; as to whether the animals or their products will find a ready market at profitable prices.

The stock-feeding solution of the problem of maintaining soil fertility is meeting with more and more favour in every part of the country. The farmers of the West, who have seen their crops gradually dwindle under single-crop farming, are awakening to the necessity for a more diversified husbandry, and especially stock husbandry. The farmers of the South are begining to realise that it will pay to split the time-honoured rotation of corn and cotton with a green crop, which may be fed to stock and the manure used to bind together the clay soils which wash so badly. One-third of the land now in cotton could be made to produce as much cotton as at present, if the other two-thirds were used for forage crops for stock. The South has the great advantage of an almost continuous grazing season. In every branch of crop production there is a renewed appreciation of the oldest and most reliable three-course rotations—the land produces crops, the crops pass through farm animals, the manure is returned to the land. Even the great practical value of green-manuring, which has been demonstrated so conclusively the past few years, has not diminished the demand for animal manures; and green-manuring is usually resorted to only when a sufficient quantity of animal manure cannot be had.

This growing appreciation of animal manures and of stock husbandry as a means of maintaining fertility is not misplaced. There are few parts of the country where live-stock husbandry, in at least one or more of its many branches, is not practicable. There is in progress an evolution toward diversified farming, which is based very largely upon the advantages of combining more or less stock husbandry with all other types of farming. Undoubtedly there are conditions when the keeping of stock is impracticable, or when the same results may be secured more advantageously by the use of green-manures, by buying animal manure from others, or by using commercial fertilisers. But these cases are few as compared with the great majority of American farms upon which stock husbandry, in some form, ought to be one of the chief means of maintaining fertility. Remember the Flemish proverb: "No grass, no cattle; no cattle, no manure; no manure, no crops."

THE EXCRETORY THEORY OF SOIL FERTILITY

There has been advocated during the last two or three years a new theory of soil fertility, especially as it relates to the rotation of crops. In the foregoing pages are presented the most commonly accepted beliefs and practices concerning soil fertility; what it is and how it may be increased and maintained to best advantage. Now comes a radically different interpretation of the nature of the problem from a few scientists, whose conclusions have been reached after extended study and are therefore entitled to a very careful hearing.

Do Plants Excrete?—The most important point in the new theory of soil fertility is the positive statement that the roots of plants do excrete substances that correspond in function to the excretions of animals. This is used to explain the value of a rotation of crops. We have been accustomed to believe that the reason why a rotation of crops results in increased yields is because the different feeding habits of the crops bring a larger area of soil under tribute, and equalise the demand upon it; because it improves the texture of the soil; because it alleviates weediness, disease and other difficulties. The new explanation is that the benefit of rotating crops is not due so much to those factors—although their importance is not denied—as to the fact that a rotation puts a new kind of plant into a soil that has become clogged with the excretions of the old crop and which has therefore become so "unsanitary" that the old plants cannot grow well. The new plant is not injured by the excretions of its predecessor and so makes a vigorous growth.

The second radical change of view that the new theory introduces is in regard to the action of manures and fertilisers. We have been believing that the value of supplying manures and fertilisers to the soil is that they actually enrich it with the plant food they contain and that this plant food that we apply is actually needed by the crop and is used by it. The new conception is that manures and fertilisers are valuable chiefly because they aid in renovating the soil, or in cleansing it of the plant excretions, or "toxic" matter, although they do supply plant food. In other words, fertilisers are chiefly beneficial not because they enrich soil but because they purify it. They act not upon the plants but upon the soil; they purify the soil from the excreta of the crop that has been grown and so affect the growth of the crop that is to be grown.

No soil physicist would champion a theory that so completely controverts our generally accepted beliefs unless there were abundant and weighty evidence to prove that it is at least plausible. It will be impossible to give here more than a bare summary of the abundant evidence submitted in support of the new theory. Briefly stated the main lines of argument are:

1. Practically all soils, including those that now produce poor crops or are said to be worn out and supposed to be exhausted of available plant food, are really rich in available plant food.

2. The cause of their unproductiveness, then, is the condition of the soil, not its chemical content. The problem of soil fertility is not concerned so much with the amount of plant food in the soil as with the condition of the soil.

3. Plants excrete from their roots poisonous substances which are to the plants what manure is to animals—the wastes. If the same kind of plant is grown continuously on the same land, the soil becomes so clogged with this plant manure that this kind of plant will no longer thrive in it, but other kinds of plants will.

4. A water-culture of an unproductive soil—an exact duplication of the soil water in that soil upon which plants feed—will not grow plants well until the impurities in it have been removed with carbon black; after this is done plants grow very vigorously in it. The chemical composition of the water-culture is the same as that of the soil water of the unproductive soil in the field.

5. Humus is Nature's carbon black. If an abundance of humus is present in the soil it absorbs these plant excrements and the soil is kept in a sanitary condition.

6. Commercial fertilisers are valuable not merely

89. HARROWING THE SUMMER FALLOW

Summer fallowing is now practised in the United States chiefly in the arid and semi-arid regions, under "dry farming." It rests the land, stores water and accumulates available plant food. But weeds are likely to collect, the use of the land is lost for that season, and there are other disadvantages. It is now seldom practised as a means of maintaining fertility

90. HAY THAT WILL SOON BE BALED AND SHIPPED TO THE CITY

The plant food in the hay is then lost to the farm. But if the hay were fed to cattle, most of the plant food in it is recovered in the manure. In selling crops we sell the fertility of the land

91. CLOVER FOLLOWING WHEAT—ONE OF THE COMMONEST ROTATIONS IN THIS COUNTRY

A rotation of crops is necessary to the highest success in most types of farming. If possible include a legume, as clover, in every rotation for the plant food they contain, but also for their cleansing action upon the soil. Manures benefit the soil chiefly because the humus in them cleanses the soil.

7. The practical application is to rotate crops, and to use farm manures and green manures, which supply the humus that cleanses the soil of plant excretions. In the wild the soil cleanses itself by the constant addition of decaying plants.

The clash between the current belief and the new belief is mainly this: The prevailing belief explains the unproductiveness of soils that the chemist finds to be very rich in plant food by saying that the soil is in poor texture and hence has not the conditions of warmth, aëration and moisture that are essential to plant growth. The new conception explains the same situation by saying that the worn-out soil has become unsanitary because of an accumulation of excretions from the roots of plants, not enough humus being present to absorb them.

These two interpretations of the cause of infertility are radically different, but there is no dispute about the remedies. In either case they are good tillage, a rotation of crops and the addition of humus to the soil in the form of farm manures and green manures. In either case these remain the most valuable means of maintaining the fertility of farm soils. So the farmer will continue to rotate crops, and to use barn and green manures, unmindful of the controversy that is being waged in the scientific world concerning the exact way in which they benefit the soil.

CHAPTER XII

GREEN MANURING AND WORN-OUT SOILS

ONE of the most significant phrases that has recently come into our agricultural vocabulary is "Keep the soil in good texture." The older farmers of to-day heard nothing about this in their early years, although many of them were skilful in securing the results now expressed by these words. Like many another idea in agriculture, good texture has been talked about and exploited to a degree that is not, perhaps, commensurate with its real importance in the successful tilling of the soil. Good texture, like the liming of soils, is but one of many important factors that enter into that most complex problem of modern agriculture—how to maintain the fertility of the soil. However, it is a subject that is not generally understood by those who till the soil, and one that cannot be overlooked or disregarded without loss. There are thousands of acres of land that produce indifferent or unprofitable crops for no other reason than that the soil is poor in texture.

WHAT IS MEANT BY "GOOD TEXTURE"

Land is in good heart or good texture when it is in the right physical condition for growing crops. This means that it possesses the qualities expressed by such common farm words as mellow, loose, friable, porous, easy to work; and is not hard, cloddy, lumpy, leachy. It is not concerned with the mere richness of the soil in plant food, but it is concerned with the way in which that plant food is served to the growing crops. It does not mean the amount of water that a soil contains, but it does mean the facility with which that water is presented to the crop. In other words, good texture means that the machinery of the soil is well oiled and in running order; not that there is plenty of raw material—plant food—in it, out of which a profitable crop can be manufactured. In the language of the farm, the texture of the soil is the way it "works up." Everybody who has handled soil knows exactly what is meant by that.

HOW NATURE SECURES GOOD TEXTURE

There are several ways of putting in good texture a soil that has become cloddy, stiff, and in "bad heart." The most practicable way, usually, is Nature's way—to keep it filled with humus.

"Humus" is another word that is fast becoming established in the vocabulary and in the practice of the successful farmer of to-day. "Humus," "green manure," and "good texture" express a trinity of agricultural ideas that are improving our farming more than anything else except, possibly, plant breeding.

Although the term humus is now in common use, there is much haziness about the conception that underlies it. The best illustration of the use of humus is found in Nature's farming. Here is a piece of virgin soil. For centuries it has nurtured herbs, grasses, vines, shrubs, trees. In numberless cycles plants have been born upon it, have grown to maturity, reproduced their kind, died, decayed, and have returned to the soil. From their substance have sprung other plants. Each year the soil becomes richer from the return of its children and is able to nourish lustier offspring. It may thus come to have upon it great trees, standing so high and so thick that we wonder how such a thin, rocky soil can support them.

Then a farmer clears the land, uproots the stumps, subdues the herbage, and plants corn. For a few years, perhaps for many years, the crops are large; but after a while they begin to dwindle. The farmer then seeks to maintain his yields by applications of fertilisers. These help some, but do not seem to restore the land to its early productive power. The farmer begins to wonder where the trouble lies. How can his pygmy crops of grain exhaust the soil more than the great forest crop of Nature's farming? He takes a sample of his soil to be analysed. The chemist tells him that the soil contains enough of all the necessary plant foods to grow seventy-five bushels of corn per acre for several hundred years. Yet the yield has fallen from sixty to forty bushels per acre, and applications of fertilisers, though they increase the yield considerably, do not secure the results of fifty years ago. Why is this?

A Farmer's Logic.—The farmer, and I assure the reader that he is not hypothetical, then began to notice more carefully the growth of crops on different parts of his farm. One season he noticed a bigger growth of corn in a certain spot. He remembered that the thresher was set up on this spot two years before and a considerable amount of fine straw and chaff had remained on the ground and had been plowed under. He recalled that last spring the plow had pulled easier and the soil

92. LOSS OF FERTILITY BY EROSION

The finest and richest soil from this field of winter wheat is being washed into the creek. Such land ought to be in sod or, at least, the drills should run crosswise of the slope

93. A GEORGIA FIELD THAT ONCE PRODUCED A BALE OF COTTON PER ACRE, NOW RUINED BEYOND REDEMPTION BY GULLYING

Shallow plowing, the lack of humus, and carelessness about "breaks" brought this about

94. RICHNESS RUNNING OFF IN THE BOTTOM OF THE DEEP FURROW MADE BY RIDGING THIS COTTON

Some day this land will be called "worn out"

95. A "BREAK" OF CORN STALKS USED TO CHECK GULLYING

Note that this one collected much soil until a new gully formed over it. Hay, cotton stems, brush, weeds, etc., are also used. Many Southern hill farms need attention in this matter all the year had worked up mellower on this spot. This gave him an idea. The chemist had also told him that he could buy of a fertiliser dealer all the plant food that there is in a ton of good cow manure for two dollars, yet this farmer knew from experience that he could get better results on his land from one ton of manure than from five dollars' worth of any commercial fertiliser he had ever bought. Perhaps the manure had other values besides its plant food value.

He went to the cow pasture and kicked over a heap of dry cow dung that had lain there many months. Evidently the rains must have washed out practically all its plant food. The substance that remains is mostly indigestible vegetable matter that the cow has eaten; it is fibrous, holds water like a sponge, and is easily incorporated with the soil. He knows that it is good for plants, though it contains little or no plant food.

Following this clue, the farmer went to his woodland. Beneath the living plants about him are the dead and decaying trees, underbrush, herbage, leaves. He can barely trace upon the ground the outline of a one-time forest monarch that is slowly passing into mould, and already nourishes a thrifty colony of mosses and ferns. Beneath the carpeting leaves is the rich, black, forest mould. It is made of the leaves, branches and trunks of a generation ago. It holds water like a sponge. Upon it Nature is growing a crop that must be many times more exhaustive of plant food than any crop of maize.

The farmer came to this conclusion: "It is this decaying vegetation that my soil needs. My farm has been cropped with corn, oats and potatoes for fifty years. No vegetation has been returned to it except the stubble and roots of the grain, the roots of the potatoes and a few weeds. For fifty years my father and I have been exhausting the soil of its vegetable matter. No wonder the soil gets cloddier and harder to work every year; it needs more of this material to separate the particles and make it looser and more fibrous. I know why it suffers more from drought than it used to—it has not enough of the spongy material in it to hold the moisture. I am going to try growing some crop to plow under and decay in the soil. I believe it is the lack of this material more than the lack of plant food that reduces my yields."

The farmer who made these remarks to me, about eight years ago, has since then more than verified the accuracy of his conclusion. Each year he now devotes a portion of his farm to clover, vetch, field peas, rye, rape, or some other crop that fits into the rotation, and plows under the herbage. His soil is growing richer and his fertiliser bill has been cut in two. Soil that formerly was lumpy, "run together," and baked is becoming mellow and in good heart; its texture has been improved by the addition of humus.

This farmer is only one of thousands who now make use of "green manure," as such a crop is called, for the improvement of their lands. I once heard a speaker at a Farmers' Institute say: "The key to maintaining the fertility of the soil is to have plants decaying in it all the time, as is the case in uncleared land." This statement of the problem is forceful and practical. He did not mean, of course, that humus alone can maintain fertility. No amount of green-manuring can enrich a soil in the mineral plant foods—potash and phosphoric acid—and there are many soils that are exhausted of these. Fertilisers and manures must be used to make good this loss. But he did mean that a majority of the soils that now produce unsatisfactory crops, and are said to be "worn out," need the humus that comes from decaying plants more than mere additions of plant food. This practice is becoming a noteworthy feature of American farming.

HOW HUMUS BENEFITS THE SOIL

Humus benefits the soil in several ways. Its greatest benefit is in improving texture. Mix a little leaf mould, gathered from the woods, with a pailful of light, sandy soil; it gives the soil more "body," and makes it less leachy. Add leaf mould to a pailful of stiff clay soil that clods, bakes and cracks in the field; the clay becomes more porous and works up better. Wet it and it does not puddle. These same results farmers secure, on a commercial scale, in their fields.

The relation of good texture to the fertility of cloddy land lies in the uselessness of the clods. The root hairs of plants feed on the outside of the smallest particles of soil. If, therefore, a large proportion of the soil is lumpy and in bad heart the feeding area or "pasturage" is reduced that much. This is why we hear about plant food being "locked up" in lumps—it is where the plants cannot get to it. This is why it is said, and truly, "Fining the soil may be equivalent to fertilising it." One way of fining the soil, and hence of increasing its productive power, is to improve the texture by adding humus.

Storing the Rain.—Another benefit that humus confers upon a soil is that of increasing its power to hold moisture. A sand may contain enough plant food for a crop, but the crop will not grow because the sand cannot supply the plant with water—it is too leachy. Plants not only need water to drink, but water is also needed to carry food that is dissolved in it to the plants. Soils deficient in humus dry out quickly in a time of drought. There may be an abundance of plant food in the soil, but it is useless for the time being if there is not enough moisture to dissolve it and carry it to the plant. Where do you find fish-worms in a "dry spell?" I dig in the moist soil beneath the chips of the old woodpile. Chips have decayed there in the soil for years. It is full of humus, and moisture, and worms. Is not the soil blacker, richer, and more moist where the currant bushes have been mulched every year with manure or straw? So in the larger operations of the farm, the addition of humus to a soil from which it has been "burnt out" by years of clean tillage has a marked effect in increasing the power of that soil to hold moisture.

Humus Enriches the Soil.—When a plant decays in the soil it returns to the soil practically all that was taken from it. But there are additional benefits. In the decay of the plant certain acids are formed that help to dissolve some of the unavailable, or unpalatable, plant food in the soil. All humus is a store of nitrogen; green-manuring is the cheapest means of maintaining the supply of this plant food. If the plants grown for green-manuring are "legumes" they are especially valuable for adding nitrogen.

TWO KINDS OF GREEN MANURE

Almost any herbaceous plant has some value when plowed under as a green manure. The weeds that get a foothold in the garden and cornfield in late summer serve one useful purpose in this way. But the trouble with weeds for green manure is that we cannot depend upon them. They come in where they have a mind to, not as we desire. Usually they are rank in the hollows, where the soil is rich and needs no humus, but shun the knolls, where the soil is hard and needs humus badly. Sometimes weeds may be turned to good account for green-manuring, but usually a special crop must be grown.

There is a distinction between crops for this purpose. They may be "leguminous" plants or "non-leguminous." A leguminous plant is one that, among other characteristics, bears its seeds in a certain kind of a pod, called by botanists a "legume." Peas, beans, clovers, vetches, alfalfa, soy beans, cowpeas, are examples of leguminous plants commonly used for green-manuring. If it is known that the soil is more or less lacking in the plant food, nitrogen, a leguminous crop should be grown for plowing under in preference to a non-leguminous crop, like rape, buckwheat or rye. Through the little warts or nodules on their roots leguminous plants may feed upon the nitrogen that is in the soil air, instead of drawing upon the supply that is in the soil. When these plants are plowed under, therefore, the soil is enriched with the nitrogen that they have gathered. The plants themselves are richer in nitrogen, and have a higher feeding value, when the nodules are on their roots.

This wonderful process of "nitrogen-fixing" has far-reaching practical application. The bacteria in these nodules, which can be seen in various sizes on the roots of most legumes, are so small that it would take 10,000 of them placed side by side to measure an inch. Yet these tiny germs save the farmers of this country millions of dollars that would otherwise have to be spent for fertilisers containing nitrogen.

If the soil does not need nitrogen, but does need humus, a non-leguminous crop like rye or rape may be grown. The leguminous plants, however, are the great soil "renovators." The clovers in the North and the cowpea in the South have built up thousands of acres of soil and vastly increased their producing power. Most of these plants, especially clovers and alfalfa, benefit the soil in still another way; they deepen it through their deep-rooting habit. Clover roots bore down into the soil several feet, bringing up and using plant food that is beyond the reach of the roots of most field crops. This is handed over to the surface soil when the plants are plowed under. But some soils will not grow clover. The kind of crop that should be grown for green-manuring, and how to grow it, depend upon the special conditions of each farm.

WHEN A GREEN-MANURING CROP MAY BE GROWN

If the soil is badly "run down," and the land can be used for a green-manuring crop without sacrificing too much, the crop may occupy the ground the entire season or even for several seasons, as when red clover is sown in the spring, cut the following year and the second crop of that season plowed under. As a rule, however, it is more practicable to grow green manures between other crops, or as a part of a definite system of rotation. The rotations listed in the Appendix point out many ways in which a green-manuring crop may be grown without losing time. The effort should be to have a "green crop" in the rotation every few years, or at least a sod to plow under occasionally; for there is humus and richness in a sod as well as in a crop grown especially for plowing under.

Catch Crops and Cover Crops.—There are two ways of introducing a green-manuring crop for part of a season. One is the use of a "catch crop," which is grown during the season between the time when one money-making crop is harvested and another planted. Catch crops are used most by market gardeners.

Another way is to use a "cover crop," which is sown late in the season after the main crop is out of the way, so that it makes some growth in the autumn, and perhaps in early spring also. A cover crop not only adds humus to the soil but it also protects the soil from heaving in spring. It catches and holds the soluble plant food that would otherwise be lost in seepage; this is returned to the soil when the crop is plowed under in spring. It also catches the snows and drys out the soil earlier in spring. One of the commonest cover crops is rye sown in corn or cotton at the last cultivation.

Cover crops are now extensively used in fruit growing. In addition to their other benefits, cover crops in the orchard make the trees mature their wood and fruit buds earlier in the fall and so lessen danger of winter injury. There are hundreds of ways in which a green-manuring crop may be introduced, depending largely upon the system of farming and the value of the land. It does not pay to allow land to lie bare and idle, unless necessary to store water in arid farming. Keep it busy. Fill in the chinks between the money crops with catch crops or cover crops that will maintain fertility; and, if engaged in staple-crop farming, endeavour to include a green-manuring crop in the general rotation.

FERTILISING VALUE OF ROOTS AND STUBBLE

It is not always necessary to plow under the entire crop in order to gain substantial benefit from green-manuring; in fact, it is seldom practicable to do so. The roots and stubble of a mature crop of cowpeas or clover contain about one-third of the soil-improving value of the crop. It is usually more practicable, particularly with leguminous crops, to harvest the hay, especially if it is fed on the farm and the manure used to enrich the farm. Thirty-five per cent. of the soil-improving value of red clover is in the roots and stubble left after the crop is cut. If the crop is fed or pastured, and the manure returned to the land, the soil gets from 80 to 90 per cent. of the full manurial value of the crop, while the farmer also gets its full value for feeding—a case of eating your cake and having it too. Stock husbandry is the key to many pleasant surprises like this.

GREEN MANURES NOT COMPLETE FERTILISERS

Green-manuring alone cannot be expected to maintain the fertility of the soil on most farms, although it will contribute very largely to that end. When crops are grown and turned under there is no

96. A FIFTEEN YEARS' GROWTH OF LONG-LEAF AND JERSEY SCRUB PINES ON A SOUTHERN HILLSIDE FARM

This land was cropped until it gullied so badly that it was almost useless. Reforesting the land is the best remedy for erosion in many cases. The loblolly pine and black locust are especially valuable for this purpose in the South

97. A HILLSIDE THAT GULLIED BADLY UNTIL COVERED WITH BERMUDA GRASS AND LESPEDEZA

These hold the soil perfectly. There are many cultivated slopes that ought to be seeded

98. THE DENSE TURF OF BERMUDA GRASS

This is the great soil-binder of the South. It takes complete possession of a pasture in two or three years, and is valuable for feeding. It spreads like "quack grass" actual gain of plant food, except nitrogen if leguminous crops are grown. No green manures return to the soil any more potash and phosphoric acid than they took from the soil. No matter how long and how skilfully green-manuring is conducted, it will not enrich the soil with one pound of the mineral plant foods, although it may make the mineral foods already in the soil more available, which may amount to the same thing, so far as crop production is concerned. A sharp distinction should be made here: green-manuring may actually enrich the soil in nitrogen, but it cannot enrich the soil in potash and phosphoric acid; it may, however, so improve the texture of the soil that plants can use more of the potash and phosphoric acid already there.

When we remember that most farm soils, even the poorest, contain tons of plant food, we can believe that in practical effect, though not in reality, green-manuring may enrich the soil in all the plant foods. The mere amount of plant food in the soil is nothing to us: it is the ability of the soil to transform this material into plants that interests us. Green-manuring helps the soil to do this as no other farm practice does, except the use of barn manures. We cannot expect green-manuring to relieve us of the necessity for buying and using the mineral plant foods; but we do expect that, in certain systems of farming, it will make unnecessary the purchase of nitrogen, and that it will greatly reduce the amount of the mineral plant foods that need be applied.

INOCULATING THE SOIL

Under some conditions a leguminous crop that is plowed under may make the soil richer by a hundred or more pounds of nitrogen; under other conditions it may add little if any nitrogen to the soil except that which it has drawn from the soil. In order that a legume may gather nitrogen from the air there must be "nitrogen-fixing bacteria" in nodules on its roots. If the legume is grown in a soil that has never been used for that crop, or not for several years, there may be none of these bacteria in the soil. If there are none the crop will not thrive, or very few nodules will be found on the roots, and when there are no nodules nitrogen is not gained. If a leguminous plant is dug up and no nodules can be found on the roots, one may be reasonably sure that the plant is not gathering from the air the plant food that costs fifteen cents a pound in commercial fertilisers, but that it is living on the nitrates in the soil.

Inoculating With Old Soil.—If no bacteria are present, they must be supplied. A few of them often cling to the seeds of the crop, sometimes enough to inoculate the soil quite thoroughly after one or two crops of the legume have been grown in it. Usually, however, it is best to inoculate with soil taken from a field on which that particular crop has been grown successfully. This soil contains millions of the germs; when it is broadcasted or drilled in, the bacteria are spread and will find the roots of the leguminous crop when it is planted. From 400 to 800 lbs. of soil is sufficient. It is best to take the soil several inches below the surface and in a part of the field on which the plants had many nodules the year previous. The practice of sprinkling old soil over a new field has given luxuriant crops of legumes after failures to get a satisfactory stand.

Inoculating With Artificial Cultures.—Another way to introduce the needful bacteria is to buy one of the several artificial cultures. Of these, "nitro-culture" is probably most widely known. These preparations contain a large quantity of the bacteria somewhat as a yeast-cake contains the bacteria that make bread rise. The "soil yeast-cake" is dissolved in warm water and this water sprinkled on a quantity of soil, which is then distributed on the new land. Very uncertain results have attended the use of nitro-culture and similar preparations; in some cases the soil has been inoculated with bacteria very successfully; in other cases no beneficial results have followed. It is evident that the method of preparing these cultures has not yet been perfected. Undoubtedly the use of artificial cultures of this and other beneficial bacteria will some time become common and successful, but at present the safest way is to get old soil if it can be had.

Some of those who are exploiting these preparations have not made it clear, as they should, that inoculating the soil with this material assists none but leguminous crops to secure nitrogen; and, furthermore, that it may help to enrich the soil in no plant food except nitrogen. The "yeast-cake" idea appeals strongly to the popular imagination and the most absurd claims are sometimes made for the artificial cultures. Soil inoculation is but one of many means of maintaining fertility, and usually it is a very incidental means.

Each Crop has Different Bacteria.—Not one kind of bacteria performs this service, but many—a different kind on each leguminous crop. According to present knowledge, the bacteria that aid clover to feed on nitrogen from the air, do not aid alfalfa, cowpeas or any other crop. This means that one must get old soil, or an artificial culture, for each kind of leguminous crop grown. It is probable that the several kinds of bacteria will be found to be more or less interchangeable, but the safest way is to get the kind that go with the crop to be grown.

It is often found that the first year a leguminous crop is grown the stand is poor and the growth unsatisfactory; or that there are few nodules on the roots, showing that little nitrogen is being secured. But the second year the crop will be better and the roots have more nodules, because the bacteria have increased. In growing leguminous crops, therefore, it is often best to re-seed on the same land until the soil becomes well filled with bacteria. Often if a poor stand of clover or alfalfa is plowed and the land at once re-seeded a much better stand is secured.

Poor Soils Benefited Most.—If the soil is already quite well supplied with available nitrogen leguminous plants growing in it get very littlenitrogen from the air; they will draw upon the nitrogen in the soil. Leguminous plants live on nitrogen of the air only when they have to; when there is very little nitrogen in the soil. Cowpea plants on poor soil usually have many more nodules on their roots than cowpea plants on a rich soil; showing that the former are living mainly on the nitrogen of the air, while the latter are living mainly on the nitrogen in the soil. Even on a soil already rich in nitrogen, leguminous crops do return more nitrogen to the soil than they draw from it; but the poorer the soil the more nitrogen there is added to it. The same crop of cowpeas may add 100 lbs. of nitrogen to the soil or 25, according to the extent to which the plants have been obliged to get nitrogen from the air. This calls attention again to the peculiar

99. SOIL IN POOR TEXTURE

It needs more humus to make it mellow

100. ON LEFT, A CLOD OF CLAY SOIL; ON RIGHT, DECAYING STEMS AND LEAVES, WHICH BECOME HUMUS

Mix the humus with the clay and note improvement. The same thing can be done in the field, on a larger scale, by plowing under a green manure

101. NODULES, OR TUBERCLES, ON THE ROOTS OF SOY BEAN

In these live the bacteria that may take nitrogen from the soil air, and turn it over to the plant. Only "leguminous" plants—as clover, pea, cowpea—can do this

102. COWPEAS ON "WORN-OUT" COTTON FIELD

Note the tiny gullies; the fine soil has been mostly washed away. The cowpeas, when plowed under, will give body to this thin soil and enrich it value of leguminous crops for improving poor soils. These bacteria do not multiply on sour or wet soils, which is one reason why light soils are usually more benefited by green-manuring than heavy soils.

PLOWING UNDER A GREEN MANURE

It is a common mistake to allow a cover crop to grow late into the spring, and until it gets woody, before plowing it under. Too much rank herbage may dry out the soil that season. The earlier it is plowed under the more moist the soil is, as a rule, and the quicker the plants decay. If possible, it is best to plow under a green manure at least two weeks before planting the succeeding crop, so that it may partially decay. If the crop is not hardy, as oats or buckwheat, it is usually best to allow the herbage to lie on the surface during the winter, and plow it under in spring rather than to plow in the fall. Little if any of the manurial value of the crop is lost by leaving it on the ground during the winter, and it protects the surface from washing. Such crops as the cowpea and soy bean are exceptions to this because their leaves fall off and are blown away. When plowing under a large amount of herbage, a drag chain is serviceable. In general, it is much better to plow under small crops of herbage two or three times than to plow under a large quantity at one time.

Like every other farm practice, green-manuring has limitations. Some crops do poorly if planted on land where a green crop has just been plowed under. Alfalfa, wheat, rye, oats, barley, and buckwheat are among these. This is partly because the decay of a large amount of herbage in the soil results in fermentation, and the soil becomes more or less acid; and partly because the herbage loosens and dries out the soil before it has become thoroughly decayed. Potatoes and corn do not seem to mind this. In any case it is best, if practicable, not to plant a crop for at least two or three weeks after a large amount of herbage has been plowed under, but to keep the land fallow. Liming the soil at the time of green-manuring is often beneficial. If only stubble is plowed under, or a scanty crop of herbage, these precautions are not necessary.

LEGUMINOUS CROPS FOR GREEN-MANURING

Red Clover is the king of green-manuring crops, especially in the Northern States. This is partly on account of its very deep root system, which bores through, loosens and drains the subsoil and brings deep-lying plant food to the surface. It does not catch well on soils in bad heart; such soils must first be improved by plowing under rye and other coarser crops. The seeding is ten to twenty pounds per acre. In the North, seeding is in early spring or in August; in the South, September or October sowing is preferred. Usually the crop is cut or pastured one or two years, and the aftermath is plowed under. Unquestionably red clover is the most valuable plant in Northern farming, where the maintenance of soil fertility as well as the largest immediate profits, is considered. If it can be worked into a rotation to advantage this should be done. Be sure the land is not deficient in lime.

The preëminent value of red clover for improving soils is strikingly illustrated in some experiments by Henry W. Geller. Many pots of ordinary soil had added to them these materials: (1) Fresh manure, at the rate of 20 tons per acre; (2) Clover stems from an old field, dried and ground to meal; (3) Ground wheat straw; (4) Ground peat. The effect of these different forms of humus on the crop grown in the soil to which they were added, was very marked. Mr. Geller concluded, "Of all the different kinds of organic matter applied, clover liberated the most plant food"; and again, "The greatest yield was obtained from the soil to which clover was applied, it being three times as large as the yield of untreated soil; while the crop from the manured soil was twice that of the untreated soil."

The Cowpea is to the South what clover is to the North. It grows anywhere south of the Ohio river, and in some places farther north, especially along the Atlantic Coast. It is planted only in spring or summer, as frost kills it. Cowpeas may be sown after wheat, oats, or rye and the crop cut for hay in time for fall crops to be sown. The roots feed almost as deeply as those of clover and the plants thrive on a very poor soil, provided it is not too wet. It is seeded at the rate of one and a half to three and a half bushels per acre, either broadcast or drilled in, and is cultivated two or three times. The vines soon cover the ground. They are commonly cut for hay; rarely is it best to plow under the entire crop.

The cowpea is most valuable as a catch crop; it fits in nicely after the harvesting of one staple crop and before the planting of another. One of the best ways of building up worn-out cotton land in the South is to sow rye in the fall, plow it under in spring, harrow and let the land lie fallow for a month, then sow cowpeas. Cut this crop for hay and sow rye again. Three or four years of this treatment will make a marked improvement in the soil. Both of these crops thrive on very poor land. The cowpea has worked miracles on thousands of acres of Southern land; it is a great blessing to Southern agriculture.

Crimson clover deserves third place in the list of soil-improvers. It is grown chiefly along the Atlantic sea-board from Massachusetts to Georgia, and is used almost entirely as a cover crop. It is sown from the last of July to the first of October at the rate of fifteen to twenty pounds of seed per acre, either between rows of standing crops, as corn or cotton, or after the crop has been harvested. The peculiar value of crimson clover lies in its ability to grow late into the winter, and to begin growth again early the next spring, thus accumulating much herbage before the spring plowing. It gathers nitrogen most industriously during this period. It makes good winter pasture. In the South, crimson clover complements the cowpea, since it grows at a season when the cowpea does not. In the North it is equally at home and is valued highly.

Alfalfa is the greatest soil-improver of arid farming in the West. At the Wyoming Experiment Station land on which alfalfa had been grown produced $16 worth more of potatoes and oats per acre than similar land that had not been in alfalfa, and this increase was secured at no cost. In late years the culture of alfalfa has extended over many parts of the East. Wherever it can be grown to advantage, as a part of the farm rotation, alfalfa is one of the very best means of maintaining fertility, although it is grown primarily as a forage or hay crop. It prefers an open subsoil, being the most deep-rooting of any farm crop; this makes it of

103. A FIELD OF COWPEAS GROWN TO IMPROVE THE SOIL

The cowpea is to the South what clover is to the North—the great soil renovator

104. A SINGLE COWPEA VINE, TWELVE FEET LONG, ON A NORTH GEORGIA FARM

The tops will be cut for hay, but the roots and stubble, when plowed under, greatly improve the soil, as they contain a third of the soil-improving value of the plant

105. VELVET BEANS GROWN FOR A GREEN MANURE IN FLORIDA

The vines are often 30 to 40 feet long. This legume largely replaces the cowpea in Florida

106. THE RIGHT PLACE FOR A COVER CROP—TO PROTECT THE BARE GROUND OF CORN FIELD OVER WINTER

Nature's cover crop of weeds is not evenly distributed. Rye sown at the last cultivation in summer is a popular cover crop for corn unusual value in improving the soil. Seeding is at the rate of twenty to thirty pounds per acre, and after spring frosts in the North; fall seeding is preferred in the South. The sod is cut for three to eight years; hence alfalfa can be used only in a long rotation.

Other Leguminous Green Manures.—The four plants mentioned above are the great soil-improvers of America. Other crops are often or occasionally grown. Canadian field peas are frequently grown in the North, especially on rough soils, and either alone or sown with grains to support the vines. The seeding is one and a half to two bushels per acre. Market gardeners often grow garden peas, pick the pods and then plow under the vines, thus getting double value from the crop. Vetches of various kinds, particularly the smooth vetch and the hairy vetch, are often used, especially in the Pacific Northwest. Vetches are used extensively for orchard cover crops in the East. The seeding is about one bushel per acre. Hairy vetch may become a bad weed unless looked after sharply. The soy bean, also called "soja bean" and "Japanese pea," is very serviceable in many sections. It is hardier than the cowpea and can be grown farther north. When grown for soil improvment the whole crop should be plowed under, as the roots and stubble do not contain such a large proportion of the plant foods as clover and cowpea stubble. White sweet clover and lupines are sometimes grown for green-manuring.

NON-LEGUMININOUS CROPS FOR GREEN-MANURING

Rye is the most useful of plants that improve the soil when plowed under, but do not enrich it in nitrogen, not being legumes. It is commonly used as a cover crop, sown in corn, after potatoes, etc., from August first to November first, the seeding being one and a half to three bushels. It is especially valuable for building up light soils or soils in such bad texture that legumes do not thrive. Rye grows late and begins growth very early in spring, thus using and returning to the soil much nitrogen that would be leached away from bare soils at this time. It makes good winter and spring pasture. Wheat is sometimes used for the same purpose.

Oats and *buckwheat* are used when a crop is needed which will be killed by winter. Buckwheat is especially valuable for very light and poor soils.

Rape is a valuable forage and green-manuring crop, especially as a cover crop. Like rye, it grows until the ground freezes, and begins growth again very early the following spring. Winter rape, however, is not hardy in the Northern States; spring rape, especially Dwarf Essex, is valued there. *White mustard* is frequently used to improve light sandy soils and is especially useful as a catch crop. It grows very rankly in late fall and is not killed until the ground freezes. The seeding is about one-third bushel per acre. It does not become a weed.

THE RENOVATION OF WORN-OUT SOILS

How to restore productiveness to soils that have lost their power to produce profitable crops, and are said to be "worn-out," is one of the great farm problems of to-day. There are hundreds of thousands of acres of worn-out soils in the Atlantic

States. The older soils of the East, which have been cultivated, more or less, for two or three centuries, were the first to decline. Gradually the area of worn-out soils is extending westward. Even some of the Mississippi Valley soils that fifty years ago were thought to be of inexhaustible fertility, are now said to be about worn-out.

The history of the East is being repeated in the West. The virgin soils there are now said to have an inexhaustible wealth of fertility; yet sooner or later the crops on even these wonderful soils will decline. Then those agricultural freebooters whose whole idea of tilling the soil seems to be that of merely skimming off the cream of Nature's increase, will pass on to virgin soils, leaving behind land that it will take years of careful farming to bring back to its normal productiveness.

The agricultural history of our country, so far as soil management is concerned, is far from being a credit to the genius of our people. It has been marked by the most ruthless soil robbery on the largest scale that the world has ever known. Virgin lands have been cleared, their fatness wrung from them with little or no returns, until the crops have dwindled to but a fraction of the bountiful harvests of pioneer days. Then the son, who has fallen heir to the inevitable result of the spendthrift farming of his father, moves West. The most disheartening feature of all is that nine times out of ten he follows there the same course which has brought poverty to so many farm homes in the East. Western farming is as improvident now as Eastern farming has been, and still is to a considerable extent. We cannot escape from the criticism of J. J. Hill: "American farmers have barely skimmed the soil; there is little intensive farming in this country."

The problem of worn-out soils is vital now and is becoming more insistent as our agriculture ages. Fortunately the East has at last awakened to the exigencies of the situation, and is reclaiming her worn-out soils with satisfactory results. It is to be hoped that before the rich farm soils in the Mississippi Valley and westward have been brought to the low productiveness that many Eastern soils have now reached—and they are surely trending that way—Western farmers will adopt the methods of husbandry that are necessary to maintain fertility.

How to Begin the Work of Soil Improvement.—The methods that are of service in renovating worn-out soils include all the points in soil management that have been noted in the preceding chapters. Undoubtedly there are a few worn-out soils that are exhausted chemically: they are actually deficient in plant food. But most of them are worn-out physically. They are unproductive, because they have been mismanaged. This mismanagement may have consisted partly in bad handling, such as plowing too shallow, or when the soil was wet, or in not checking erosion. It is more likely, however, to be due to mismanagement as regards rotation of crops; and probably it is due most of all to mismanagement as regards maintaining the supply of humus in the soil. Most worn-out soils are in special need of humus. Green-manuring is of greater importance in the renovation of worn-out soils than any other factor.

In most cases the quickest and easiest way, to begin with, is to grow leguminous crops for green-manures. But green-manuring will be made more effective, and certainly more remunerative, if it can be associated with some form of stock husbandry, so that the crops may be fed or pastured on the place and the manure returned to the soil. Stock-feeding, not clover, cowpeas nor any other plant, is the key to the most economical maintenance of soil fertility in general farming. There are few sections of the country where it is not practicable to raise some kind of stock.

When animal manures are not available, however, green-manuring alone will improve worn-out soils, but less economically. Commercial fertilisers have little value for restoring a worn-out soil if, as is usually the case, the texture of the soil, not its chemical contents, is at fault. They are of far greater usefulness after the soil has been put into good heart by green-manuring or the addition of animal manures.

The final step in the improvement of a worn-out soil is to put it into a rotation of crops which is not exhaustive and which makes provision for a continuance of the various farm practices that maintain fertility. Thousands of acres of land in the East, thought to be worn-out, have been restored to bountiful productiveness by these methods.

CHAPTER XIII

FARM MANURES

FROM the beginning of agriculture, applications of manures have been the chief means of maintaining the fertility of farm soils. Manuring has been assisted, to some extent, by green-manuring and crop rotation. In modern agriculture increasing prominence is being given to these latter practises. But it is not likely that manuring will ever be displaced as the most widely practiced and most economical method of maintaining the fertility of the land.

The vital relation between stock husbandry and crop husbandry has been emphasised in the preceding chapter. The practical advantages of associating these two coördinate branches of agriculture are more generally admitted to-day than at any previous time. Farmers are beginning to abandon the wasteful methods of pioneer days, to curtail the present extravagant use of artificial fertilisers, and to rely more and more upon Nature's provisions for maintaining fertility and the excrements of animals—the return of plants to the soil. The first provision is discussed in the preceding chapter; the second in this chapter.

HOW MANURE BENEFITS THE SOIL

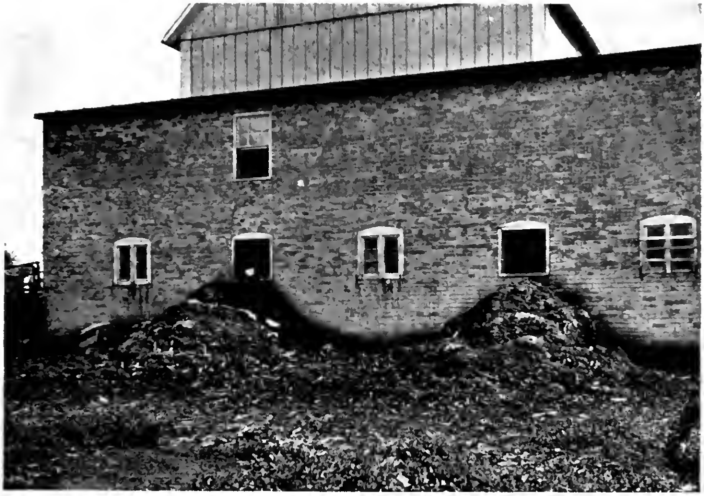
The real value of manures and their effect upon the soil were not known until quite recently; and it is altogether probable that even now we have but just begun to understand the manifold ways in which manure improves the soil. There was a time when the value of manure was thought to be only or chiefly the value of the plant food it contained. It was even said that since a ton of stable manure contains but $2 to $4 worth of nitrogen, potash and phosphoric acid, that the same amount of plant food could be obtained and applied more cheaply in the form of a commercial fertiliser. This is true; but the conclusion must not be drawn that manure might well be supplanted by commercial fertilisers. From the chemist's point of view a ton of manure may be worth but $2, because that is the value of all the plant food in it. From the farmer's point of view manure may be worth several times that amount. The farmer knows that he cannot buy $2 worth of artificial fertiliser that will give the results on most soils that one ton of manure will. This fact, which is realised by farmers everywhere, has led to a very careful investigation of the ways in which manure benefits the soil, aside from adding the small amount of plant food it contains. These supplementary benefits, which the chemist knows nothing of and does not consider in his estimates of the value of different kinds of manures, are often of far greater practical value in crop production than the plant food that the manure contains.

Manure Improves Texture of the Soil.—The chief value of manure, on many soils is not the plant food it adds but its beneficial effect upon the texture of the soil. In the preceding chapter it was shown that most farm soils, even those that are unproductive and worn-out, contain large amounts of plant food; and that the cause of the unproductiveness is more apt to be that the soil is in poor condition, or bad heart, than that it is exhausted of plant food.

One of the great functions of manure is to improve the condition of the soil, so that the plant can more readily use the plant food in it. Examine old, dry, cow dung in the pasture. The plant food in it has been mostly washed out; a spongy, fibrous material is left which, when crumbled, presents such equable conditions of moisture and temperature, that florists like to sow cineraria and other extremely fine and delicate seeds upon it. This material, which is about one-quarter of the original substance of manure—the balance being water—is composed mostly of food that the animal did not digest. When incorporated with the soil it greatly improves the texture, loosening a heavy, compact soil and binding together a light, leachy one; making the soil more friable, warmer, more retentive of moisture and more congenial to plants in every way.

In three years' experiments, King found that manured fallow ground contained eighteen tons more water per acre in the first foot of soil than similar land unmanured, while the total gain of water in the first three feet of soil was thirty-four tons. Being already fine and partially decayed, the vegetable matter in manure is at once thoroughly incorporated with the soil, becoming humus; while a green-manuring crop plowed under is converted into humus slowly. No one who has seen the almost magical improvement in a hard, clay soil by a single liberal dressing of manure can doubt that its value is largely, sometimes mostly, in its effect upon soil texture.

The Bacteria in Manure.—Aside from the humus it adds, manure benefits the soil in other ways, most of which are still imperfectly understood. It is known that manure contains countless numbers of



107. A COMMON, AND AN EXTREMELY WASTEFUL METHOD OF STORING FARM MANURES

Rains and the drippings from the eaves may wash out two thirds of the plant food in this manure before it is spread upon the land

108. THE DARK-COLOURED PUDDLE IN THE BARNYARD CONTAINS THE ESSENCE AND THE RICHNESS OF THE MANURE

No man can maintain the fertility of his farm economically if he permits such a waste

109. THE MANURE PILES FROM THIS BARN DRAIN INTO THE POND, WHICH IS COVERED WITH "DUCK MEAT" IN TESTIMONY OF ITS RICHNESS

Good for ducks, but the land of this farmer needs that fertility badly

110. MANURE WAGON, WHICH RECEIVES THE MANURE FROM THE STALLS AND FROM WHICH IT IS SPREAD ON THE LAND EACH DAY

The sooner manure is got upon the land the better bacteria that are beneficial to the soil. When the vegetable matter in manure decays in the soil certain acids and ferments are produced which have a decided influence upon the supply of available plant food. In short, the addition of manure to farm soils sets in motion a series of activities which profoundly affect the productivity of the land. All this is in addition to the plant food value of manure. It is altogether probable that we do not know half of the direct and indirect benefits of manure upon farm soils. But we do know enough about it to place its agricultural value far above its plant food value. Commercial fertilisers influence the soil almost solely in regard to its supply of plant food; farm manures influence all the soil conditions which are essential to the production of profitable crops. There is no comparison whatever between the two.

THE COMPARATIVE PLANT FOOD VALUE OF DIFFERENT MANURES

The amount of plant food in different kinds of manure depends upon the animals from which it came and the care it has received. Analyses of the excretions of various animals are given in the Appendix. It will be noted that horse manure is richer in nitrogen than either cow or hog manure. An average sample contains about 6 per cent. of nitrogen, 3 per cent. of phosphoric acid and 5 per cent. of potash. It is, however, liable to "fire fang," or ferment, unless kept compact and moist; this lowers its value somewhat. Horse manure varies in composition more than any other, because of the greater variety of ways in which it is handled, particularly as regards the use of bedding.

Cow and hog manure contain more water than other kinds and are relatively poorer in plant food, especially in nitrogen. An average sample of either contains about 4 per cent. of nitrogen, 2 per cent. of phosphoric acid, and 5 per cent. of potash.

Sheep manure is commonly richer than the manure of any other farm animal, except poultry. It is comparatively dry and since it is usually allowed to accumulate in pens, where it is tramped hard by the animals, it is less apt to suffer a loss of plant food than other kinds. Ordinarily it contains about 8 per cent. of nitrogen, 2 per cent. of phosphoric acid, and 7 per cent. of potash.

Poultry manure is the richest of farm manures, largely because it contains the semi-solid urine, and there is little waste. It is especially rich in nitrogen and phosphoric acid. An average sample contains 12 per cent. of nitrogen, 9 per cent. of phosphoric acid and 6 per cent of potash.

Average values for different manures are: Sheep manure, $4.20 per ton; mixed farmyard manure, $2.25 per ton; hen manure, $6.50 per ton; hog manure, $3.20 per ton; livery-stable manure, $2.45 per ton; cow manure, $2.43 per ton. These figures are based solely on their plant food content and do not consider the value of the manure for improving the soil in other ways.

THE QUALITY OF MANURE

The age and the condition of the animal influence the quality of manure. Manure from young animals is not as rich as that from full grown animals, because the former digest a larger proportion of their food than the latter. Cows in milk return only about 65 to 75 per cent. of the manurial value of their food in their excrements, while cows that are being fattened return 80 to 90 per cent.

The kind of food that the animal eats has a marked effect upon the richness of its manure. The more grain there is fed to them, especially such foods as wheat bran, gluten meal and cotton-seed meal, the richer the manure, since these grains are rich in protein. Animals fed solely on hay of poor quality produce manure that is much inferior to that of grain-fed animals. In short, the richer the ration, the richer the manure.

The kind and quantity of bedding used affects the value of manure, also the individuality of the animal. Some animals use a larger proportion of their food for making milk, or beef, or mutton, than others; what is not used is recovered in the manure.

HOW MANURE IS WASTED

There are still many sections where barn manure is not used upon the land, and, in fact, is considered a nuisance. In parts of Oregon farmers give away manure for the hauling, and are glad to be rid of it. In counties of California and Oklahoma manure is dumped into the river. Some Missouri, Kansas, and North Dakota farmers use it to fill up holes, or dump it in heaps beside the fields and roads. Some South Dakota farmers burn it to get rid of it. In Idaho it is frequently seen piled as high as a barn. The waste of manure in parts of the West is a painful sight to the Eastern farmer who knows that the land will soon be in need of it. On the very farms where manure is thrown away in this manner the soil is often greatly benefited by it, even now. These improvident methods, however, are becoming less and less common.

The plant food in manure is subject to serious loss. Although there may be but little plant food in manure, as compared with artificial fertilisers, yet most of it is very soluble and is easily lost, if the manure is not handled carefully. The plant food in manure is wasted in two ways; by leaching and by fermentation.

The Leaching of Manure.—No other farm practice has been discussed more than that of allowing plant food to leach from manures. One can scarcely attend a farmers' institute without hearing about it, or read a farm journal without seeing a reference to it. All this agitation has probably saved many million dollars. worth of plant food that otherwise would have been wasted. Yet is it doubtful if one per cent. of American farmers realise what they lose by neglecting to care for manures properly. One estimate places the annual loss of plant food on American farms, by leaching from manure that could easily have been prevented, as $200,000,000 or over four times what is paid each year for commercial fertilisers. If the leaks on a few farms are noted, and the number of farms in a neighbourhood that suffer similar losses are counted, one will conclude that this estimate is not too high. The saving of manures is indeed a threadbare subject; but there is such urgent need that farmers adopt better methods of handling manures that one is justified in harping upon it.

One of the most common farm scenes in eastern United States is a row of manure piles beneath the eaves of the barn. Each pile extends up to the hole or window out of which it was thrown from behind the cows or horses. Water from the roof drips upon it; rains and snows beat upon it; winds dry it. After a heavy rain the puddles in the yard are black with richness that has leached from these piles of manure. This is the fertility of the farm running to waste. Manure handled in this way may lose over half of its plant food. Roberts found that a ton of manure exposed in this way for six months lost 42 per cent. of its plant food. Another ton exposed from April 25 to Sept. 22 lost 60 per cent. of its nitrogen, 47 per cent. of its phosphoric acid and 76 per cent. of its potash, a loss in value from $2.80 per ton to $1.06. When the pile of exposed manure is finally hauled away it has lost a large part of its soil-improving value. A dark-coloured stain on the side of the barn is pretty good evidence of shiftless farming in this respect.

The loss of plant food from manure by leaching depends largely upon the climate; the wetter it is the greater the loss. In the arid and semi-arid regions it is not large; but in every case it is large enough to set every farmer to thinking how he may best prevent it.

Loss from Fermentation. Another way in which manure often loses value is by heating, or fermentation. When manure is piled up, especially horse manure, it begins to heat and decay. This fermentation is caused by the growth of bacteria. These need heat and air; the warmer the manure is, and the more loosely it is piled, so that it is full of air, the more quickly it heats. The nitrogen in fermenting manure is rapidly changed into ammonia, which escapes into the air. Every one has noticed the pronounced "smell" of manure piled up loosely and heating. It is plant food escaping.

The heating of manure also injures it in another way. Part of the vegetable matter in it, which becomes humus when applied to the soil, is burned.

The higher the manure heats, the greater is the loss. Dry, white, "fire-fanged" manure has had a large part of its humus-making material destroyed.

Loss from the Escape of Urine.—A third way in which manure loses value is by failing to catch the liquid portion. This contains more nitrogen and more potash than the dung; yet, in many cases, liquid manure is allowed to run to waste, while the dung is saved. Moreover the plant food in the liquid portion is immediately available to plants. It should be saved as carefully as the solid portions of the excrements.

HOW TO CARE FOR MANURES

Leaching usually causes more loss of plant food from manure than either fermentation or the waste of liquid manure; attention should first be given to preventing this loss. There are two ways of doing this: by hauling the fresh manure from the stable and spreading it upon the land at once; and by piling it under cover.

Hauling manure direct from stable to field involves little or no loss of fertility, as compared with storing it, and is the most satisfactory method whenever it is expedient. Usually, however, it is not expedient to do this at certain seasons of the year; it would interfere very seriously with other farm work, while the hauling of stored manure may be done to advantage in late fall and very early spring when other work is not pressing.

Usually at least a portion of the manure must be stored, especially that made during the busy months of seed time and harvest. In this case there is but one sane thing to do; that is, to pile the manure under cover. This is the only safe way to prevent leaching; a single, heavy, summer shower may leach away enough plant food from an exposed pile to pay a large part of the slight expense of covering the pile.

Covered barnyards are sometimes practicable. The animals tramp the manure and so keep it from fermenting. The cattle are exercised and watered there, in winter especially. It is necessary, however, to use a considerable quantity of bedding and to keep the yard dry. A yard 30 x 50 feet is large enough for fifteen to twenty cows, but they should be dehorned.

Manure Pits.—Another method, preferred by many, is to build shallow, covered cement pits, adjacent to the stable. Into these the manure is dumped; the liquid manure from the gutters in the stable may drain into them. In large dairy stables manure is collected on trucks or cars which are run on tracks to these pits. The pits should be large enough to hold the manure made in several weeks, or as long as it is convenient to wait before hauling it to the field. This is one of the most practicable ways of storing manure.

If a cement pit cannot be had, and the manure must be stored outside the barn, it is a simple matter to build a shed over it. But part of the liquid in the manure will drain off, and the farmer can ill afford to lose it. Therein is the great advantage of covered cement pits.

Many barns are built so that the manure can be shoved down a scuttle into a cellar. In some cases the cellar is cement-lined and excellent conditions for storing manure are thus secured. Often the cellar bottom is not cemented allowing the loss of part of the liquid manure. Cellars beneath the stable do very well, so far as the saving of manure is concerned; but there are decided sanitary objections to this method. The stable above is almost sure to be bad-smelling. Thorough ventilation and the use of gypsum will do much to alleviate this condition; but manure should be stored away from, not beneath, the animals, especially in a dairy.

The manure of animals confined in pens, as sheep and young stock, is usually stored without serious loss, if it is allowed to accumulate and an abundance of bedding is used. The manure is tramped down very firmly by the animals, all the liquid portion is absorbed, and there is little loss by fermentation or leaching.

How to Prevent Loss by Heating.—The fermentation that makes manure deteriorate in value takes place only when it is piled loosely, so that air passes through it readily. Compacting the manure, as with the tramping of animals, prevents this loss. Manure must also be only moist, not wet, in order to ferment; so that if it is kept wet with the liquid excrement, there is little likelihood that it will heat. Sometimes it is practicable to wet the manure occasionally. If fermenting manure has a small amount of fresh manure mixed with it the heating will be checked.

Methods of Saving Liquid Manure.—The simplest way to save liquid excrement is to provide plenty of bedding to absorb it. Many materials are used for bedding and these affect the value of the manure. It is commonly thought that strawy manure is not as valuable as clear manure; yet the straw in manure may have absorbed much of the liquid excrement, so that strawy manure may be really more valuable than that which contains little straw.

The objects of bedding are not only to keep the animals comfortable and clean but also to catch the urine and to increase the bulk of the manure so that it can be distributed more evenly. Straw is most generally used and is quite satisfactory. Marsh hay, cornstalks, leaves, sawdust and shavings are used more or less. The two latter should be used in moderate quantities; in large amounts they lower the value of the manure. Pine needles are believed to injure the manure. Fine, dry sand or soil is sometimes used to advantage, and occasionally peat or muck. These earthy materials have greater value for bedding than strawy materials because they absorb ammonia gas as well as liquids, and so save nitrogen and keep the air of the stable sweet.

The plan of collecting the liquid manure and distributing it upon the fields by means of a tank with a sprinkling attachment has not been found generally practicable. Ordinarily it is more satisfactory to absorb the liquid manure with bedding.

The use of bedding will not entirely prevent the loss of plant food from the stable. There is always a considerable amount of ammonia escaping, as the sharp odour about stables bears evidence. This can be prevented by using chemical absorbents which enter into combination with the ammonia, making a salt of ammonia that is not volatile. Land plaster (gypsum) is most commonly used for this purpose. Kainit and superphosphate are used to some extent, enriching the manure not only with the nitrogen they catch but also with the plant food they contain. These materials should be scattered in the stables at the rate of one to two pounds per animal daily, and also over the manure piles. Dry sand, earth, peat or muck answer quite well for this purpose.

AMOUNT OF MANURE MADE ON THE FARM

The amount of manure that will be made during a year by a given number of animals is capable of fairly accurate calculation. A common estimate is:

Horse,	12,000	lbs. of solids, and	3,000	lbs. of liquids.
Cow,	20.000	" " " "	8,000	" " "
Sheep,	760	" " " "	380	" " "
Swine,	1,800	" " " "	1,200	" " "

Another method, resulting from many careful experiments, is to multiply the amount of "dry matter" in the food for one year by 2.1 for the horse, by 3.8 for the cow, by 1.8 for the sheep. Add to these figures the weight of bedding used. Thus if a cow eats thirty pounds of dry matter a day she will produce about 30 x 3.8, or one hundred and fourteen pounds of manure a day, besides the bedding. The age of the animals, their condition and their food influence the amount of manure made.

According to Heiden's rule for calculating manure, the following quantities of cow manure may be expected from feeding one ton of the feeds named:

GREEN FEEDS

	Pounds
Corn fodder	1,590
Rye fodder	1,797
Red top	2,465
Oat fodder	2,903
Orchard grass	2,074
Timothy	2,942
Hungarian grass	2,220
Red clover	2,243
Crimson clover	1,482
Alfalfa	2,166
Cowpeas	1,260
Soja beans	2,188
Corn Silage	1,605

DRY FEEDS

	Pounds
Corn fodder	4,439
Orchard grass hay	6,920
Red top hay	6,996
Timothy hay	6,282
Hungarian grass hay	7,089
Red clover hay	6,505
Crimson clover hay	7,020
Alsike clover hay	6,935
Alfalfa hay	7,035
Cowpea hay	6,858
Soja bean hay	6,428
Millet hay	6,931

The amount of plant food in manure may also be estimated with considerable accuracy, if one knows the kinds and the amounts of foods that the animal consumes. Numerous digestion experiments have shown the amounts of the fertilising materials in various feeds and fodders that are ordinarily recovered in the manure. Knowing the amount of each feed and fodder that each animal eats, the amount of potash, phosphoric acid and nitrogen in each food, and the percentage of this that is commonly recovered in the manure, one can tell how rich the manure should be.

Most farms do not produce enough manure to dress the fields satisfactorily. Sometimes manure may be bought to advantage, especially livery-stable manure, city street sweepings, or stockyard manure. Ordinarily it will not pay to give over a dollar a ton for average barnyard or stable manure, and not this much if the haul is long. If the farm is near a town, stable manure may often be obtained for the hauling, especially if the farmer agrees to haul it away whenever necessary.

WHEN TO APPLY MANURES

No advice can be given that is generally applicable, but a few suggestions will show the great diversity of practice. In general the sooner manure is spread upon the soil after it is made, the more will the soil be benefited. But other considerations affect this point. The state of decay and the kind of crop must be considered. Rotted manure—that which has partially decayed—may be applied to better advantage in the spring than fresh or "green" manure. Rotted manure is commonly preferred for the lighter soils and fresh manure for the heavier soils. Market-garden crops, especially, prefer rotted manure, chiefly because its plant food is somewhat more quickly available than that in fresh manure, and these crops need this to make a quick start and a very rapid growth. Gardeners often make manure into a compost with leaves and vegetable and animal refuse of all sorts. The material is put into a long, low, flat-topped pile which is turned over and mixed several times. Ordinarily it is allowed to rot for two years.

One of the most common practices on American farms is to broadcast fresh manure on grass land that is to be plowed after the next crop of hay. Another is to manure heavily for corn, which does not object to large amounts of coarse fresh manure, and to follow corn with a crop that prefers to have the manure quite well rotted, as it will be after having lain in the soil a year.

Spreading Manure in Winter.—On a majority of farms most of the manure that is available is produced during the winter months when the animals are housed. Farm work is usually light at that time of the year and it would be a great advantage to spread the manure frequently during the winter rather than to wait until early spring, when roads, lanes and fields are miry and when other farm work demands attention. But some farmers fail to spread manure in winter because they think much of the plant food in it will be washed away. Usually the danger of loss is far less than is feared.

Manure spread upon the land in winter loses little of its value unless the land is quite steep so that there is considerable surface washing. If the land is fairly level there need be no appreciable loss. Manures spread at this season do not ferment, because the temperature is too low. Manure spread in winter should be applied to land on which plants are growing, as on sod or on cover crops. It is especially desirable to manure in winter land that is to be planted to Indian corn. Sometimes heavy snows make winter spreading impracticable.

HOW MUCH MANURE TO USE

In applying manure the amount of the different plant foods in it should be kept in mind; also whether it is being used chiefly to improve the texture of the soil or to supply plant food. The nature of the soil and the crop are other deciding points.

Manures are often applied too freely. Rarely is it profitable to apply over 40 two-horse loads per acre, and 25 to 35 loads is about the maximum amount under most conditions. Ordinarily farmers use from 4 to 10 cords of cow manure per acre; market gardeners, however, who grow plants under special conditions so that their methods cannot be compared with the methods of general farming, often use 30 to 50 cords per acre. A cord of fresh cow manure weighs about three tons.

Light Dressings Desirable.—If a certain field is in special need of the mellowing and enriching effect of manure, a heavy dressing may be given; but usually it is more profitable to spread 30 cords of manure over 10 acres, if 30 cords is all that can be had, than to put all of it on 5 acres. A moderate increase in yield on 10 acres is better than a heavy increase on 5 acres. The farther a field is from the barn, the less likely it will pay to haul a heavy dressing of manure to it; for manure is bulky and expensive to handle. It may be more practicable to put humus into such fields by green-manuring, and perhaps commercial fertilisers can be used there to advantage.

Although manure is a complete fertiliser, it is not well balanced since it usually contains much more nitrogen than either of the other two plant foods. An abundance of nitrogen promotes a very vigorous growth of leaves and stems, but it is not so valuable for developing seeds and fruits. Too heavy applications of manure may make the wheat lodge or the fruit soft. For this reason if only a limited amount of manure is available, it is best to use it most freely on the crops that are valued chiefly for a very vigorous growth of stem or leaf, as the grasses, clover, most garden vegetables, and forage crops. Commercial fertilisers should be used on manured soil to supply the plant food that manure is deficient in and so balance it; as by using superphosphate on land manured for cotton.

111. MANURE PILED IN THE FIELD, TO BE SPREAD LATER

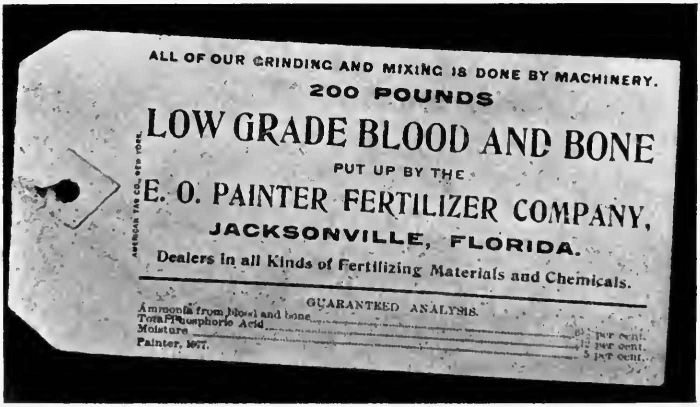
This is often more convenient than spreading direct from the wagon, but it must not be left in piles long

112. SPREADING MANURE FROM THE WAGON ON CORN STUBBLE

A manure spreader does the work more evenly but not more cheaply

113. BUYING PLANT FOOD IN SACKS

This is practicable only to supplement home resources. Be sure you know what kind of actual plant food is in the bag, and how much. Buy by analysis, not by brand



114. A FERTILISER TAG TAKEN FROM A SACK, SHOWING THE GUARANTEED ANALYSIS OF THE FERTILISER

Some of the analyses printed on fertiliser tags, while perhaps true, are apt to be misleading. The farmer should be able to figure out from the tag how much he could afford to pay for the fertiliser

HOW TO APPLY MANURE

The most practicable method in many cases, especially in winter, is to spread it direct from the wagon, cart, or sled. Fresh manure distributed from wagons in winter is not apt to be spread very evenly and should be scattered in spring with a brush drag. The manure may be dumped in piles, which are spread later. The merit of this plan is that it economises team work, so the relative cost of team and hand labour must be considered. If the manure is dumped in piles it should be spread very soon; otherwise the ground on which it is piled becomes over-rich. Some farmers leave manure in the field in piles for several months; their crops are decidedly "spotted" for two or three seasons thereafter.

Manure spreaders are of little advantage to the average farmer, chiefly because they carry such a small load in proportion to the draft, and their expense. They do, however, distribute manure more evenly than it is usually done by hand.

CHAPTER XIV

COMMERCIAL FERTILISERS

ONE OF the most striking features of American agriculture is the extraordinary rapidity with which the commercial fertiliser industry has developed. Bone, wood ashes and a few other natural products have been in use for centuries, but the first use of artificial fertilisers—the "phosphates" of the modern farmer—was about 1845. Not till after 1860, however, were they used to any great extent. The annual fertiliser bill of American farmers to-day is close to fifty millions of dollars. This is paid mostly by the farmers of about twenty of the Eastern States, for commercial fertilisers are used very little in most of the Western States.

In round numbers, we have paid about a quarter of a billion of dollars for artificial fertilisers in the last five years. In no other country are commercial fertilisers used to the extent they are here. Yet only a small per cent. of our farm soils have shown the need of fertilising. When the millions of acres of rich, Western farm lands have passed through the same history of gradual decline as those in the East —as they certainly will—what will our fertiliser bill be, a hundred years hence? Where is this enormous and rapidly increasing expense account leading us? Are the results secured by the present lavish use of artificial fertilisers sufficient to justify us in continuing the practice or is there a cheaper way of solving the problem of declining fertility?

Changed Economic Conditions.—The rapid growth of the fertiliser trade is not necessarily an indication that American farmers have preferred artificial fertilisers to farm manures. Since 1865 we have passed through great economic and social changes which have favoured the use of artificial fertilisers. The most important of these, as related to agriculture, is the rapid growth of cities. This has developed the great market-garden, fruit and trucking interests which are the chief users of commercial fertilisers. Market-garden and truck farmers, many of whom are, of necessity, located near cities on high-priced land, often find it impracticable to keep stock or give up the use of their expensive land for green-manuring, even for a short season. They must keep a money-crop growing upon it every day of the season. With them, the soil is merely the medium for transforming the plant food which they spread upon it into merchantable crops. The modern market garden near a large city more nearly resembles a manufacturing establishment than a farm. Under such conditions, the use of artificial fertilisers, as well as purchased manures, is probably the most practicable course to pursue. There are also many instances where artificial fertilisers are seemingly almost indispensable—as, for example, in the culture of pineapples on the almost barren sands of eastern Florida.

The staple-crop farmer, however, has not these peculiar economic conditions to contend with. The time-honoured methods of maintaining soil fertility by green-manuring, by a rotation of crops and by the use of animal manures—he can use if he chooses. Unquestionably commercial fertilisers will be used more and more extensively in market gardening and in the culture of special crops and on certain soils; but the indications are that their use in general farm practice as a chief source of fertility is on the wane, while the use of the more natural resources, green-manuring and farm manures, is on the increase. Often artificial fertilisers have been used to remedy temporarily the effects of poor texture, due to mismanagement. Commercial fertilisers, if used at all in general farming, should be applied sparingly and as a supplement to natural resources, not as the main source of fertility.

WHAT COMMERCIAL FERTILISERS ARE MADE OF

The term is usually applied simply to materials which contain the essential plant foods—nitrogen, potash and phosphoric acid. These are found in many materials: some are mineral products, as nitrate of soda, muriate of potash, phosphate rock; some are animal products, as dried blood and tankage, which are wastes from the slaughter houses, and boneblack, which is a refuse in refining sugar. These raw materials are combined in various ways, and in different proportions, perhaps treated with acids. One brand of commercial fertiliser may be made of two or three of these raw materials; another may contain many kinds.

Complete and Incomplete Fertilisers.—Commercial fertilisers are either "complete" or "incomplete." A complete fertiliser contains all three of the essential plant foods; an incomplete fertiliser contains but one or two. Most fertilisers sold in this country are complete. The reason for this, from the manufacturer's point of view, is obvious. He knows little or nothing of the kind of soil upon which the fertiliser will be applied, or of its needs as regards plant food. In order to be sure that it will be of some benefit on all soils, then, it is necessary for it to contain all three plant foods. But, as will be emphasised later on, very few soils really need additions of all three; some need only one. In such cases the use of a complete fertiliser is wasteful.

Many Brands.—Most fertiliser manufacturers sell many brands, or different combinations of raw materials. Some firms sell as many as forty-five brands, each one, presumably, different from all the others, and designed to meet the needs of certain soils or certain crops. Thus we have Smith's Mortgage-lifter Fertiliser, Jones' Sure-crop Fertiliser, Brown's Special Potato Fertiliser, White's Corn Fertiliser, and so on. In one year 1,112 brands of fertilisers were sold in the State of New York alone. In most states the number is from 150 to 300.

State Supervision of the Fertiliser Trade.—How shall the farmer know which of these many brands to choose? Some of them are just what his soil and crops need; some would be almost worthless to him. The national and state governments have now come to the assistance of the farmer in this important matter. State laws specify that no fertiliser manufacturer or dealer shall sell any brand of fertiliser in any state, either direct from the factory or through an agent, until the brand has first been registered with some appointed authority, usually the Director of the State Experiment Station. The manufacturer is further required to put a tag on each bag of fertiliser, giving an analysis of its contents specifying the amount of each of the essential plant foods it contains. Every year the Experiment Station of each state in which fertilisers are used extensively, collects samples of the fertilisers offered for sale in that state, and analyses each one to see if it contains as much plant food as the manufacturer claims that it does. If it is found to contain less than the guarantee on the tag specifies, the manufacturer is subject to prosecution.

The effect of this state supervision of the fertiliser trade has been very satisfactory. The general standard of the business has been raised. Each year the Experiment station of each state publishes a bulletin listing all the brands of fertilisers that have been registered for that year, also the guaranteed analysis of each as shown by the manufacturer's tag, and the actual value, as shown by analyses at the Experiment station. Farmers who use fertilisers should get these bulletins.

Studying Fertiliser Tags.—Some of the guarantees printed on fertiliser tags are misleading. The real analysis is sometimes obscured by adding to it statements of valueless materials that the fertiliser contains, and by repeating the real analysis in another form, thus making the buyer who is not skilled in such matters think he is getting more for his money than he really does. Roberts states that the following guarantee was on a fertiliser sold in New York:

	Per cent.
Total bone phosphate	30 to 35
Yielding phosphoric acid	14 to 16
Soluble bone phosphate	22 to 26
Yielding water-soluble phosphoric acid	10 to 12
Total available bone phosphate	26 to 30
Available phosphoric acid	12 to 14
Insoluble bone phosphate	2 to 4
Yielding insoluble phosphoric acid	1 to 2

What a lot of dust-raising! Doubtless it is all true; and the manufacturer has complied with the law that requires him to state on the tag the amount of plant food contained in the fertiliser. But the buyer wants to know just one thing—how much available potash, phosphoric acid, and nitrogen the fertiliser contains. This tag should have read:

	Per cent.
Soluble phosphoric acid	10
Reverted phosphoric acid	2

That is all there is in it of value to the farmer. The most reliable manufacturers print on their tags a bare statement of the amount of actual plant food the fertiliser contains.

Repetitions in Guarantees.—Another fertiliser tag reads:

	Per cent.
1. Ammonia	3 to 5
2. Available phosphoric acid	11 to 13
3. Total phosphoric acid	15 to 19
4. Total bone phosphate	27 to 30
5. Actual potash	12 to 14
6. Muriate of Potash	18 to 22

There are several repetitions in this complete fertiliser. Contrary to the common idea among farmers, ammonia is not nitrogen; it is only four-fifths nitrogen, the other fifth being hydrogen, which has no value as a fertiliser. It will be necessary to multiply the 3 per cent. of ammonia by .82, the actual percentage of nitrogen in ammonia. This shows that there is 2.46 per cent. of the plant food nitrogen in this fertiliser, instead of 3 per cent. There is 11 per cent. of available phosphoric acid in this fertiliser, as shown in No. 2, out of the total amount of phosphoric acid it contains, 15 per cent., indicated in No. 3. We are not concerned about the bone phosphate in No. 4, because this is merely a repetition of the figures given for phosphoric acid; 46 per cent. of bone phosphate is actual phosphoric acid, and this has already been stated in Nos. 2 and 3. There is 12 per cent. of actual potash, which is that found in the muriate of potash and repeated in No. 6. The guarantee of this fertiliser might better be:

	Per Cent.
Nitrogen	3
Available phosphoric acid	11
(furnished in bone phosphate)	
Insoluble phosphoric acid	4
Potash	12
(furnished in muriate of potash)	

Always take the lowest per cent. given. Rarely does a fertiliser contain more than the minimum amount of plant food stated in the guarantee.

THE FORMS OF PHOSPHORIC ACID

The way in which the amount of phosphoric acid is stated is one of the most common sources of confusion. The nitrogen and potash in commercial fertilisers are mostly soluble and available to plants. But the phosphoric acid in fertilisers is more complex. It is usually not alone but combined with different amounts of lime, making "phosphates of lime" or "phosphates." On fertiliser tags one will find these terms: "available phosphoric acid," "soluble phosphoric acid," "insoluble phosphoric acid," "reverted phosphoric acid."

"Available" and "soluble" phosphoric acid are the same, for only plant food that is soluble in soil water can be available, or useful to plants. This valuable kind of phosphoric acid has but one part of lime with it and two parts of water:

Lime
Water —— Phosphoric acid.
Water

This is the kind of phosphoric acid that is found in superphosphates. It quickly dissolves in water and plants can use it at once. In some guarantees it is called "water-soluble phosphoric acid."

"Insoluble phosphoric acid," on the other hand, has three parts of lime to one of phosphoric acid, and has no water, thus:

Lime
Lime —— Phosphoric acid.
Lime

This is the kind of phosphoric acid found in fresh bones and in the various "rock phosphates" taken from the mines. Since it cannot be dissolved in water, insoluble phosphoric acid has no value whatever as a plant food unless it can be changed into soluble phosphoric acid. As bones rot in the ground the insoluble phosphoric acid in them slowly becomes soluble, losing part of its lime. A quicker way to change this into plant food is to treat it with acids, which is the way superphosphates are made.

In studying fertiliser guarantees, remember that the "insoluble phosphoric acid" is not plant food and cannot become so until it has been made soluble. When applied to the soil, insoluble phosphoric acid may gradually become soluble. Hence it is customary, when figuring on the value of a fertiliser, to count the insoluble phosphoric acid as worth about one-half as much as the soluble. Some chemists, however, do not consider it worth even that much.

The "reverted phosphoric acid" on fertiliser tags is intermediate between the soluble and the insoluble, thus:

Lime
Lime — Phosphoric acid
Water

Reverted means turned back; this is phosphoric acid which was once soluble but is gradually becoming insoluble, since more lime has been added to it. If soluble phosphoric acid in the soil is not quickly used by plants it tends to revert. In this condition it is not quite as readily used by plants. However, the reverted phosphoric acid given in fertiliser analyses may be considered about as valuable as the soluble. Sometimes a tag will read "phosphoric acid soluble in ammonium citrate." This is reverted phosphoric acid, ammonium citrate being the weak acid used by chemists to dissolve it.

Points that the fertiliser buyer should remember when studying guarantees are:

1. Look for the percentage of *nitrogen*. If the analysis gives the percentage of ammonia, remember that it is but four-fifths nitrogen. If the analysis says "equivalent to nitrate of soda," remember that but 15 per cent. of nitrate of soda is the plant food nitrogen.

2. Look for the percentage of *potash*. If the tag says, "equivalent to sulphate of potash," or "equivalent to muriate of potash," remember that but half of sulphate or muriate of potash is the plant-food potash.

3. Look for *water-soluble phosphoric acid* or *available phosphoric acid*. Insoluble phosphoric acid has half value; reverted phosphoric acid is slightly less valuable than soluble.

4. Look out for re-statements in the fertiliser tags, thus:

	Per cent.
1. Bearing total bone phosphate	30 to 35
2. Yielding phosphoric acid	14 to 16
3. Soluble bone phosphate	22 to 26
4. Yielding water-soluble phosphoric acid. .	10 to 12
5. Total available bone phosphate	26 to 30

Statement No. 4 is the only one worth considering; the others are mainly re-statements in another form. "Equivalent to" or "Yielding" usually means that the plant food in the fertiliser has already been stated in the guarantee in another form. To convert one material into another, when there is repetition, use the following table:

To convert the guarantee of			*Multiply by*
Ammonia . . .	into	Nitrogen	.82
Nitrate of soda .	"	Nitrogen	.16
Bone phosphate .	"	Phosphoric acid . . .	.45
Muriate of potash	"	Potash	.63
Sulphate of potash	"	Potash	.54

5. Pay no attention to anything in the guarantee that is not plant food. The amounts of "moisture," "silicic acid," "carbonic acid," "magnesia," "alumic oxid," "ferric oxid," and other materials that the fertiliser contains are of no interest or value to the buyer.

CALCULATING THE VALUE OF A FERTILISER FROM THE ANALYSIS

The value of a commercial fertiliser is based solely upon the amount of plant foot that it contains. Animal and green manures are often quite valuable for their effect upon the condition or "heart" of the soil; but commercial fertilisers have little or no value in this respect. When buying a fertiliser the farmer should consider just two things; the amount of plant food in it and what it costs per pound in this form. It is a simple matter to estimate the value of a commercial fertiliser from its guarantee, provided the guarantee is not too confusing. Suppose a fertiliser is offered with the following guarantee:

	Per cent.
1. Ammonia	2 to 4
2. Available phosphoric acid	10 to 12
3. Total phosphoric acid	14 to 17
4. Equivalent to bone phosphate	30 to 37
5. Potash	9 to 11
6. Equivalent to sulphate of potash	16 to 20

The first thing to do is to draw a line through statements 4 and 6, because 4 is a repetition of 2 and 3, while 6 is a restatement of 5. The ammonia must now be reduced to nitrogen by multiplying 2 per cent. by .82, giving 1.64, the percentage of actual nitrogen in the fertiliser. Since there is 14 per cent. of phosphoric acid in the fertiliser and but 10 per cent. of this is available, the inference is that the other 4 per cent. is insoluble. A simplified statement of the contents of this fertiliser is:

	Per cent.
Nitrogen	1.64
Available phosphoric acid	10
Insoluble phosphoric acid	4
Potash	9

The number of pounds of each plant food in a ton of this fertiliser is then determined:

1.64% of 2,000 lbs.= 32.8 lbs. of nitrogen in a ton.
10% of 2,000 lbs.=200 lbs. of available phosphoric acid in a ton.
4% of 2,000 lbs.= 80 lbs. of insoluble acid in a ton.
9% of 2,000 lbs.=180 lbs. of potash in a ton.

The trade values of the different plant foods in commercial fertilisers vary slightly from year to year but generally a pound of nitrogen is worth seventeen cents; a pound of potash four cents; a pound of available or water-soluble phosphoric acid, four and a half cents; this is what the several plant foods can be bought for in raw fertilising materials. The valuation of this particular fertiliser is:

	Per ton
Nitrogen, 32.8 lbs. @ 17 cents per lb.	$ 5.57
Available phosphoric acid, 200 lbs. @ 4½ cents per lb.	9.00
Insoluble phosphoric acid, 80 lbs. @ 2¼ cents per lb.	1.80
Potash, 180 lbs. @ 4 cents per lb.	7.20
Total value per ton	$23.57

Such a fertiliser may cost $36 per ton, or more. The difference between this sum and $23.57, the actual value of the plant food in it, covers the cost of mixing, bagging, handling and the profit. On an average it costs about $8 per ton to mix, bag, and handle a ton of fertiliser before it finally reaches the buyer, and allow a fair profit for all concerned. If $8 is added to the actual plant food value of a fertiliser, as determined from the guaranteed analysis, the buyer knows what would be a fair price to pay for the fertiliser.

LOW-GRADE FERTILISERS EXPENSIVE

To meet the demand for a cheap fertiliser—a lot of fertiliser for the money—many manufacturers sell "low-grade fertilisers" for $15 to $26 per ton. But it costs as much to mix, bag, and handle a ton of fertiliser containing $15 worth of plant food as it does a ton of fertiliser containing $30 worth of plant food. Furthermore, the cost of applying it to the land is greater, since more has to be applied to give a certain result. Usually plant food can be bought more cheaply in a concentrated, or "high-grade fertiliser" than in a low grade. Even though a low-grade fertiliser may contain some high-grade materials, as sulphate of potash and nitrate of soda, the plant food in it usually costs more because this is weighed down with so much useless bulk. The farmer cannot afford to pay for bulk. Every pound of material in a ton of fertiliser which is not plant food adds to the price which the farmer must pay for the plant food. Usually the more concentrated the fertiliser, and hence the higher the price per ton, the cheaper it is. But one cannot make a mistake in buying a low-grade fertiliser if he figures on the guarantee.

ADVANTAGES OF HOME-MIXING OF FERTILISERS

It is a convenience to buy fertilisers mixed and ready to apply, provided the buyer examines the guarantee and finds that he can buy plant food in this fertiliser about as cheaply as though he bought the raw materials and mixed them himself; and provided, too, that this brand of fertiliser contains the several kinds of plant food in the right proportions for the soil and the crop to be grown. But this is not usually the case. Few farm soils need applications of all three plant foods; many need but one. Many brands of commercial fertilisers contain all three and the farmer may be buying plant food that his soil does not need, and so wasting his money.

The raw materials out of which commercial fertilisers are made, may be bought and mixed on the farm. There are several advantages in doing this as compared with buying commercial brands. The most important one is that of being able to use but one or two of the plant foods, as is found necessary, and to gauge the proportions of each to suit the needs of the soil and the crop. There is also a saving in the cost of plant food, because the raw materials are mostly concentrated, and there is less expense in handling them. Added to this is the difficulty of always determining with absolute certainty the exact amount of plant food in a brand of commercial fertiliser owing to the ambiguous wording of many guarantees.

On the other hand, it is sometimes difficult to buy these raw materials; they are not so generally distributed over the country, as brands of mixed fertilisers. Again, the mixed fertilisers are apt to be ground more finely than the unmixed. If a man uses but little fertiliser, it is likely that he will find it more expedient to buy a commercial brand; but if he uses a considerable amount it may be cheaper for him to buy plant food in the raw materials, not mixed. Most fertilizer dealers sell the raw materials as well as mixed fertilisers.

The following raw materials are most commonly used:

SOURCES OF NITROGEN

Nitrogen is the most costly of the three plant foods. For this reason special attention should be given to the means of producing it on the farm, as discussed in the two preceding chapters. The chief commercial sources fall into two classes: the "nitrates," which are salts; and "organic nitrogen," which is the nitrogen in plant and animal materials, as cottonseed meal, dried blood, etc. Plants can feed on a nitrate but not on organic nitrogen. It is necessary for the plant or animal product to thoroughly decay, during which process the organic nitrogen in it is changed into a nitrate, before plants are able to use this kind of food. This shows the value of knowing the source of the different plant foods in a fertiliser.

Nitrate of Soda (*Chili Saltpetre*), is the chief commercial form of nitrogen as a nitrate. Large deposits of this salt are found in the arid sections of South America. It contains from 15.5 to 16 per cent. of nitrogen. Nitrate of soda is dissolved in soil water almost immediately and becomes at once available as plant food. For this reason it should not be applied to land until the crop is planted, or just before. It is especially valuable for giving crops a quick start, and for promoting a luxuriant leaf and stem growth.

Dried Blood is collected from slaughter houses. Red blood contains 12 to 14 per cent. of nitrogen, and black blood 6 to 12 per cent. This material decays very quickly in the soil, so that its plant food is quickly available for crops. It is one of the best sources of nitrogen.

Cottonseed Meal usually contains 7 per cent. of nitrogen, together with 1½ to 2 per cent. each of potash and phosphoric acid. The nitrogen in it is as quickly available to plants as that in dried blood. This material can often be used to best advantage, however, by feeding it to stock and recovering most of the nitrogen in manure.

Sulphate of Ammonia is a by-product in the manufacture of boneblack, illuminating gas and coke. It usually contains about 20 per cent. of nitrogen, being the most concentrated source of this plant food. The nitrogen in it is nearly as quickly available to plants as that in nitrate of soda. It should not be mixed with muriate of potash, as the muriate causes a loss of ammonia.

Less important sources of nitrogen are the following animal products: hoof meal, dry ground fish, tankage, Peruvian and other guanos, horn and hoof meal, wool and hair waste, dried meat or meal; and two vegetable products, linseed meal and castor pomace. These materials are usually obtained with greater difficulty and are less valuable for the farmer unless he is so situated that he can buy them advantageously. The amount of plant food in each of these is given in the Appendix.

SOURCES OF PHOSPHORIC ACID

The principal sources of phosphoric acid are phosphate rocks and bones. In most cases the phosphoric acid is in combination with lime, making a phosphate of lime. Only a fertiliser that contains phosphoric acid is a "phosphate," but this term is often applied by farmers to all fertilisers. For many years bones were the main source of phosphoric acid and they are still largely used.

Raw Bone is that which has not been treated in any way, except by grinding. It should contain about 4 per cent. of nitrogen and 22 per cent. of phosphoric acid; but only 5 to 7 per cent. of the phosphoric acid is soluble, the remainder being insoluble. For this reason the phosphoric acid in raw bone is but slowly available to plants, its usefulness extending over several years.

Boiled and Steamed Bone.—Most of the bone used as fertiliser has been boiled or steamed to free it from fat. The fat is objectionable in a fertiliser and is valuable for soap; the meat contains nitrogen and is used in making glue. Boiling or steaming reduces the amount of nitrogen in the bone, so that it contains about 28 to 30 per cent. phosphoric acid and only about $1\frac{1}{2}$ per cent. of nitrogen. About 6 to 9 per cent. of the phosphoric acid is soluble. Boiled or steamed bone, however, can be pulverised much finer than raw bone and this greatly increases its value for immediate use. It is much used in mixed fertilisers and is especially valuable for meadows.

Both raw and boiled or steamed bone are sold under various trade names, as "meal," "dust," and "fine ground bone." These terms refer to fineness, not to composition, and there is no uniformity; the "bone meal" of one manufacturer may be as fine as the "bone dust" of another. The finer it is, the better, since it decays more quickly.

Dissolved Boneblack.—Raw bones are burnt until they become "animal charcoal" and are readily crushed into a fine powder. This "bone black" is used in refining sugar. It is then turned over to the fertiliser dealer, who finds that it contains 32 to 36 per cent. of phosphoric acid, mostly insoluble, and a small amount of nitrogen. Boneblack is sometimes used directly as a fertiliser, but more commonly is treated with oil of vitriol to make the phosphoric acid in it more soluble. The resulting product is "dissolved boneblack" which contains 15 to 17 per cent. of soluble phosphoric acid and is one of the most important of the phosphates. Some superphosphates are dissolved boneblack.

Rock Phosphates.—Other sources of large amounts of phosphoric acid are mineral deposits in South Carolina, Georgia, Florida, Tennessee and Canada. These rock phosphates are mostly the fossil remains and the dung of animals, chiefly fish-eating birds. This rock differs widely in composition. South Carolina rock phosphate, discovered in 1868, is most generally used. It contains 26 to 28 per cent. of phosphoric acid, most of which is insoluble. This South Carolina rock is ground very fine and sold as "floats." Floats are often used for certain crops, especially on moist soils rich in humus. This raw, cheap, slowly-available mineral phosphate may often be used instead of the high-priced, quickly-available superphosphates, especially on perennial crops like fruit trees and grasses. It is becoming quite a common practice to use floats for the main supply of phosphoric acid and to supplement it with small amounts of a superphosphate.

Florida rock phosphate, discovered in 1888, is more variable in composition than that found in South Carolina. It contains from 18 to 40 per cent. of phosphoric acid. The phosphoric acid in it seems to be much more slowly available than that in South Carolina rock. Tennessee rock phosphate, discovered in 1894, contains 30 to 32 per cent. of insoluble phosphoric acid and is used chiefly in making superphosphates.

Phosphate Slag, also sold as "Thomas slag," "Thomas phosphate meal" and "basic slag" is a by-product in the manufacture of Bessemer steel, phosphorus being an impurity in iron ore. The slag is ground to a fine powder and contains 15 to 20 per cent. of phosphoric acid, much of which is soluble in soil water and so is quickly available for plants. This material is considered one of the best phosphates for general use, especially on moist soils rich in humus and poor in lime. It is produced in this country in considerable quantities.

Superphosphates.—Any phosphate, either bone or mineral, which has been treated with acid to render its phosphoric acid more soluble is called a superphosphate. One popular superphosphate—dissolved boneblack—has been mentioned. Dissolved bone, made by treating raw ground bone with sulphuric acid, is another. It contains 13 to 15 per cent. of available phosphoric acid and 2 to 3 per cent. of nitrogen. The most common superphosphate is that made by treating ground rock phosphate with sulphuric acid. The great fault of the raw rock and raw bone phosphates is their slowness; plants derive little benefit from them the same season that they are applied. To overcome this, the manufacturer mixes some strong acid with them, usually sulphuric acid. This makes most of the phosphoric acid in them soluble.

Contrary to the belief of some, a well-made superphosphate contains no free acid that will make the ground "sour." The acid used in making it is all combined with lime, making gypsum, which is itself a valuable dressing for some soils. However much difference there may be in the agricultural value of raw bone phosphates and raw mineral phosphates, a superphosphate made from one is as good as a superphosphate made from the other, per pound of phosphoric acid; the kind of raw material does not count after it has been treated with acid.

Besides dissolved bone and dissolved boneblack, which are the common bone superphosphates, "plain superphosphate," "acid phosphate," and "dissolved rock" are standard sources of this plant food. These are all superphosphates made from rock phosphate. That made from South Carolina rock is most common; it contains 12 to 14 per cent. of soluble phosphoric acid. The "double superphosphate," containing about 45 per cent. of available phosphoric acid, is not used much in this country.

It is more difficult to decide what material to buy as a source of phosphoric acid than either of the other plant foods. The first question that arises is whether a raw bone or a raw mineral phosphate should be bought, or a superphosphate. The relative cost of the plant food in the different materials, its availability, and the special needs of the soil and crop must determine this. A pound of phosphoric acid can be bought in raw rock phosphate for two and a half cents; in raw ground bone for four cents and in a superphosphate for five to six cents. Crops that mature quickly, including most vegetables, need quickly available fertilisers; while plants which grow for several seasons, as fruit trees and grasses, are able to get along with a certain amount of slowly available fertiliser. The cruciferous plants, as cabbage and turnip, appear to do very well on the raw phosphates. Use as much of the slow-acting, but cheap, raw phosphates as practicable. Oftentimes a combination of superphosphate, for quick results, and raw phosphate, for general enrichment, is the best solution of the problem.

SOURCES OF POTASH

There are few commercial sources of potash; the most important are wood ashes and the German potash salts.

Wood Ashes.—Until the discovery of the potash salts, this was the chief potash fertiliser. Wood ashes are often leached with hot water to extract the potash for soap-making and other purposes. The ashes remaining contain only one-third as much potash as before—usually but 1 or 2 per cent.—besides 1½ per cent. of phosphoric acid and 30 per cent. of lime. Unleached wood ashes, if well cared for, should contain 6 to 9 per cent. of potash, 2 per cent. of phosphoric acid, and about 32 per cent. of lime. Hardwood ashes are richer than softwood ashes.

Wood ashes are so variable in composition, according to their source, impurities and care, that one should buy them only on a guaranteed analysis. A good sample is worth about twenty cents a bushel for the plant food in it, which is almost all immediately available. In addition, wood ashes have an important indirect value, due to the lime they contain. The price paid for them, however, should be based on their plant-food content only. In this case the potash in them costs a trifle more than that in the German salts; but the indirect benefit of wood ashes is often so marked that their great popularity as fertiliser is justified. When they can be bought at about the same price per pound of plant food, or a little more, as other potash fertilisers, prefer the ashes.

Besides wood ashes, cotton-hull ashes are a valuable but limited source of potash; lime-kiln ashes usually contain less than 1½ per cent. of potash and 1 per cent. of phosphoric acid; coal ashes contain no plant food whatever but may benefit the soil by improving the texture.

German Potash Salts.—Deposits of crude potash salts in Germany were discovered in 1859. Mining was begun in 1862 and the product of the mines is now about 750,000 tons a year. The supply seems inexhaustible. Three kinds of German potash salts are commonly used in this country: kainit, muriate of potash, and sulphate of potash.

Kainit is one of the crude salts, just as it comes from the mines. It contains about 12 per cent. of actual potash and 33 per cent. of common salt, together with other salts. This extremely large percentage of salty material makes kainit undesirable for the heavier soils and for some crops; but it is beneficial to light soils, and to certain crops, as asparagus, that appreciate salt. Since it contains so low a per cent. of potash, a pound of potash in kainit costs more than a pound in the refined salts. For this reason it is rarely used except when its indirect benefit, because of its saltiness, is needed. *Sylvinit,* another crude salt, is very little used in this country.

Muriate of Potash is used in the United States more than any other potash fertiliser. It is very highly concentrated, containing about 50 per cent. of actual potash. Potash in muriate at $40 per ton costs four cents a pound, which makes this the cheapest source of potash.

There are two occasions when muriate of potash should not be used. Certain crops, notably tobacco, sugar beets, onions, and potatoes, are quite noticeably injured by the chlorine which this salt contains in large amounts. Again, if the soil is deficient in lime, heavy applications of muriate of potash will be likely to aggravate the trouble. If it is necessary to apply potash every year, alternate the muriate with the sulphate, or with wood ashes, and give the land an occasional dressing of lime. Never mix muriate of potash with sulphate of ammonia; the latter will lose part of its nitrogen. The muriate is especially valuable for the lighter soils, because it attracts moisture.

Sulphate of Potash is bought in two forms, "high grade" and "low grade." The former contains 51 to 53 per cent. actual potash, which in this form costs four and one-half cents a pound at the current price of $45 a ton. High-grade sulphate of potash can be used safely for all crops. Unlike the muriate it does not increase the loss of lime from the soil; although the potash in it costs a trifle more than that in the muriate, the sulphate is generally preferable for this reason. It is especially preferable for tobacco, sugar beets, onions and potatoes. Low grade sulphate of potash contains about 26 per cent. of potash combined with magnesia, which has a beneficial effect on some soils. But the potash in it costs more than in other forms, so that it is not used much in this country.

Many other materials are occasionally used as fertilisers, such as tobacco stems and stalks, wool and hair waste, seaweed, crude fish scrap, etc. The amounts of food in the most common of these are given in the Appendix.

MIXING THE RAW MATERIALS

If but one plant food is to be applied, the material is put upon the land as it comes from the dealers; if two or three are to be applied, the materials must be mixed. The mere mixing requires little skill, but it is very important to get the right proportions of the different plant foods in the mixture. We will suppose that excellent results have followed the use of 1,000 pounds per acre of a certain brand of fertiliser containing 4 per cent. of nitrogen, 8 per cent. of potash and 6 per cent. of phosphoric acid; but it is found that the plant food in this fertiliser costs more than it can be bought for in raw materials. This means that for each acre, a mixture containing 40 pounds of nitrogen, 60 pounds of potash, and 80 pounds of phosphoric acid is needed. By referring to the figures of the amounts of plant food in each fertilising material, we find that the 40 pounds of nitrogen may be obtained in 250 pounds of nitrate of soda, or 200 pounds of sulphate of ammonia, etc. The 60 pounds of potash may be obtained in 120 pounds of sulphate of potash, or in 114 pounds of muriate of potash, etc. The 80 pounds of phosphoric acid may be obtained in 533 pounds of dissolved South Carolina rock, or in 250 pounds of Florida phosphate, etc. If sulphate of ammonia is found to be the cheapest source of nitrogen, sulphate of potash. of potash, and dissolved South Carolina rock.of phosphoric acid, the mixture would be:

200 lbs. sulphate of ammonia
120 lbs. sulphate of potash
533 lbs. dissolved South Carolina rock

853 lbs. for an acre; larger quantities in proportion.

It often happens that some fertilising materials which can be bought to advantage contain more than one kind of plant food. Thus a good sample of unleached ashes should contain 8 per cent. of potash and 2 per cent. of phosphoric acid; in such a case each plant food should be figured out independently. If a fertiliser containing 10 per cent. of potash and 5 per cent. of phosphoric acid is needed, and ashes can be bought very reasonably, it will only be necessary to add to the ashes a sufficient quantity of muriate of potash, and of superphosphate, for example, to make a fertiliser having the desired analysis.

The actual mixing of fertilisers is easily done. The right quantities of the several materials are dumped upon a tight, smooth floor and are shovelled over until thoroughly mixed. The mixture may then be put through a sieve. It is best to keep the several ingredients separate until a short time before the fertiliser is needed. Any fertiliser containing ammonia should not be mixed with lime, as lime attacks ammonia and nitrogen escapes. If highly concentrated fertilisers are mixed, as muriate of potash and bone ash, it is often desirable to add a quantity of some other material, not plant food, as dust, dry soil or land plaster. This gives the mixture greater bulk so that it can be distributed much more evenly, especially if light applications are to be made. The saving in buying raw materials and mixing them at home is often 25 to 40 per cent. over the cost of the same amounts of plant food if bought in the average manufactured article.

WHAT KINDS OF FERTILISER TO USE

There are two great problems in using commercial fertilisers. The first is, "What kind and what amounts of plant food does my soil need?"

The second, "In what form can I buy each plant food cheapest?"

What and how much fertiliser to apply as a fertiliser depends upon the deficiency of the soil, the needs of the crop, the system of farming, and kindred matters.

Soil Analyses as a Guide to Fertilising.—If the crops are unsatisfactory, and this cannot be wholly explained by a poor texture of the soil, a deficiency of available plant food may be suspected. But what kind of plant food, and how much fertiliser will it pay to apply? The first thing that many farmers do is to send a sample of the soil to a chemist to be analysed; for, they argue, if crops grow on plant food in the soil, surely an analysis of the soil should show just what it needs. But the chemical analysis of a soil rarely gives reliable information about the best way to fertilise it. The analysis of a certain soil may show that there are 5,000 pounds of phosphoric acid in the upper nine inches, but it does not and cannot show how much of this vast amount is soluble, or in such a form that plants can use it; this makes a great deal of difference, from the farmer's point of view. An analysis often points out glaring deficiencies and gives hints that may be valuable in fertilising a soil; but it is by no means a reliable guide, and it usually bears no relation to the method of fertilising which will be found most profitable on that soil.

It is generally understood, however, that certain types of soils have special needs. Clay and other heavy soils are usually rich in potash, but poor in phosphoric acid; sandy soils, and all others deficient in humus, lack nitrogen; peat and muck soils need potash and phosphoric acid more than nitrogen, especially potash.

Questioning the Soil.—A good farmer will not long be satisfied to fertilise solely on hearsay evidence. He will observe the effects of different fertilisers on his own crops and, gradually learning the peculiar needs of his soil, will fertilise accordingly. It is not necessary to lay out an elaborate series of plot experiments with fertilisers in order to determine with considerable accuracy what fertiliser pays best on a certain soil. In many cases it is enough merely to test different fertilisers as a part of the regular farm practice; in other cases it will pay to lay out fertiliser plots. In either case, the testing should be done methodically and the results should not be interpreted too hastily.

A common way of testing fertilisers is to use different kinds indiscriminately, until one is found that answers the purpose. This hit-or-miss method is usually unsatisfactory. Another way is to apply each of the three plant foods separately and in combinations. This is an exact and reliable method. In these experiments it is customary to use nitrate of soda, sulphate of potash, and superphosphate as the sources of plant food, since these materials each contain but one kind of plant food.

These fertilisers may be applied to different rows of plants, or to plots of the same size. Plots one rod wide and eight rods long, containing $\frac{1}{20}$ of an acre, are a convenient size. The plots should be long and narrow, so as to cover inequalities of soil. If the land is sloping, run them up and down the slope. Make every condition in the several plots as nearly alike as possible, except as to the kind of fertiliser applied. It is best to leave between plots a strip of land at least four feet wide, which is unfertilised; this prevents the fertiliser applied to one crop from affecting the crop in an adjoining plot. The full experiment would look like this:

Plot 1	Plot 2
Nitrate of Soda, 8 lbs.	Acid Phosphate, 16 lbs.

Plot 3	Plot 4
Nothing	Sulphate of Potash, 8 lbs.

If it is desired to test the value of different combinations of plant foods, add:

Plot 5	Plot 6
Nitrate of Soda, 8 lbs. Sulphate of Potash, 8 lbs.	Nitrate of Soda, 8 lbs. Sulphate of Potash, 8 lbs. Acid Phosphate, 16 lbs.

Plot 7	Plot 8
Nitrate of Soda, 8 lbs. Acid Phosphate, 16 lbs.	Stable Manure

Plot 9	Plot 10
Sulphate of Potash, 8lbs. Acid Phosphate, 16 lbs.	Lime

The fertiliser should be applied broadcast and harrowed in lengthwise, not crosswise, of the plots. The amount used should be somewhat larger than in the field at large; if the plot is $\frac{1}{20}$ of an acre satisfactory amounts are 8 pounds of nitrate of soda, 8 pounds of sulphate of potash and 16 pounds of superphosphate. The fertiliser may be mixed with dry soil or sand in order to distribute it more evenly. Throughout the season give all plots the same care.

In comparing the crops grown under the different methods of fertilising it is well to take only the inside rows of each plot, if no unfertilised strips have been left between plots, because the outside rows may have been affected by the fertilising of the adjacent plots. The yields of the several plots may be measured for comparison. Such a test as this, even though not carried out in every detail, gives valuable results to the man who is obliged to use commercial fertilisers. It is well to repeat the experiment two or three years and upon the same land if possible.

The Needs of Different Crops.—The chemical analysis of a crop is of very little practical value to the man who wishes to know what fertiliser to apply to that crop. The proposition looks plausible, however. The chemist tells the cotton farmer that the crop of cotton plants which produce 190 pounds of lint per acre draws an average of 40 pounds of nitrogen, 16 pounds of phosphoric acid and 25 pounds of potash from the soil. The farmer will then apply these amounts of the plant food each year, but adding a little more, because probably part of it does not reach the crop.

But the chemical analysis of a crop is no more reliable as a guide to fertilising that crop than the chemical analysis of a soil. Both are useful hints, and may point out striking needs or deficiencies, but other factors are much more important. An experiment at the New York State Experiment Station, for example, showed that a fertiliser containing nearly the proportions of plant food used by the potato plant was much less useful than one containing very different proportions, based on the experience of observing growers. An abundance of phosphoric acid in the soil contributes more to the profitable growth of the cotton crop than either of the other plant foods; yet an analysis of the cotton plant shows that it contains less phosphoric acid than either nitrogen or potash. The needs of the soil and the needs of the crop cannot be studied separately and independently with any degree of satisfaction; they are coördinate and complementary.

Crops do differ, however, in their demands upon the soil. A knowledge of the special needs should be helpful to the man who does not have the results of a home fertiliser test to guide him. A few general suggestions follow:

The small grains—wheat, rye, oats, and barley, are especially benefited by an abundance of nitrogen and of phosphoric acid. The latter is especially needed in the development of grains.

Indian corn, a very exhaustive crop, is more apt to need applications of the mineral plant foods especially phosphoric acid, than of nitrogen.

Forage crops, including the grasses and grains grown for forage, but not clovers, are most apt to need nitrogen.

The clovers, including all legumes, need potash and phosphoric acid, but not nitrogen; they also draw heavily on lime.

Root and tuber crops are more variable in their demands. Potash should be the most important ingredient of a fertiliser for sweet and Irish potatoes—the sulphate is preferred to the muriate; phosphoric acid for turnips and nitrogen for beets and carrots. Root crops need quick-acting fertiliser.

Fruits.—The period of growth of tree fruits is extended over a longer time than other farm crops, and so slow-acting fertilisers may be used upon them to advantage. The small fruits, however, as strawberries and raspberries, must have quick-acting fertilisers. Potash is of special importance in a fruit fertiliser.

Market-garden crops in which the chief object is to secure the crispness and tenderness that comes from a rapid growth, as celery, radishes, cabbage, lettuce, etc., must have an abundance of quick-acting fertiliser, particularly of nitrogen.

Cotton especially enjoys an abundance of phosphoric acid.

These general suggestions on the fertilising of different crops merely indicate what many people have found profitable. They are subject to many exceptions, depending upon the kind of soil on which the crop is grown. So it all comes back to the elemental problem of questioning the soil. This will ever be an experiment for each farmer; no one else can perform it for him.

THE RELATIVE IMPORTANCE OF THE THREE PLANT FOODS

Phosphoric acid is regarded by many as the most important of the three plant foods; not because it is more essential to the profitable growth of crops, but because it is more likely to be lacking in ordinary soils than either potash or nitrogen; and, furthermore, because the commercial supply of phosphoric acid is apparently more limited than that of the other two plant foods. In most cases the supply of nitrogen may be maintained without difficulty with barn manure and green-manuring. Potash is found more in the straw than in the grain; the grain, which is rich in phosphoric acid, is commonly shipped away from the farm while the straw remains. From the point of view of the future supply, then, phosphoric acid is the most important of the three plant foods.

From the point of view of the plant, however, one food is as important as another. Plant foods are often spoken of as though each one performed certain definite functions; as "Potash makes fruit," "Nitrogen makes stem and leaf growth," and "Phosphoric acid fills out the grain." Undoubtedly each of the three plant foods does exert a special influence in one of these several directions, but all are essential to the well-being of the plant. "Fertilising for fruit" or "fertilising for grain" or "fertilising for growth" is apt to be one-sided and unsatisfactory fertilising. The plant as a whole is the unit; fertilise to make a symmetrical, well-developed plant; not for an abnormal development of any part.

WHEN TO APPLY COMMERCIAL FERTILISERS

This depends first of all upon the solubility of the fertiliser. One would not apply nitrate of soda, which dissolves almost immediately in soil water, in the fall; much of the nitrogen in it would be leached from the soil by spring. But one might apply raw bone meal in the fall, because this becomes available quite slowly. The more soluble a fertiliser is, the more necessary it is to apply it at or about the time it will be needed most by the crop.

As a class, the nitrogen fertilisers are more quickly soluble and more apt to be lost by leaching than the other plant foods; they should usually be applied in the spring or during the summer, as needed. The potash and phosphoric acid in fertilisers are not subject to serious waste; they remain in the soil until taken out by plants, combining with lime, silica and other minerals in the soil. This is called the "fixing" of these plant foods. It usually takes place within a week after the fertiliser is applied. With the exception, in some cases, of raw bone and raw mineral phosphates, it is best to apply fertilisers in the spring.

The special needs of crops also influence the time for applying fertilisers. Many crops need a special stimulus at certain times and under certain conditions. Thus, if wheat on light land has passed through a severe winter it may need an application of nitrogen in the spring, in addition to the regular fertiliser provided for it the fall previous. Or again, beets that are being forced for bunching will profit by several light dressings of nitrogen at intervals of two weeks, instead of putting all the fertiliser into the ground at planting time.

HOW TO APPLY FERTILISERS

The method of applying fertiliser is mostly a matter of expediency. In a majority of cases it is best to broadcast it over the entire surface after plowing and before the last harrowing. Most of the common fertilisers suffer no loss if left on the surface, but it is generally considered best to work all fertilisers into the soil, because this mixing brings the plant food within reach of the roots more quickly. There are some fertiliser distributors on the market that do the work cheaper than it can be done by hand; fertilisers may also be drilled in.

Whether part or all of the fertiliser should be put into the hill or drill depends upon the soil and the crop. Nothing is lost by broadcasting it, for the roots of the crop will lay every foot of soil under tribute; but an early start may be gained by putting part of the fertiliser in the hill or drill, if it is quickly available. This is especially profitable on light and poor soils, particularly if but little fertiliser is used; and for market garden crops, as earliness counts for more with them than with general farm crops. In any case only a part of the fertiliser should be put in the hill or drill; most of it should be broadcasted. With grains, however, all the fertiliser may be drilled in. Fertilisers used on hoed crops that are growing should be cultivated in between the rows. A nitrogen fertiliser applied after the crop has started should not be put on when the leaves are wet; if much of the fertiliser sticks to the leaves, injury may follow.

The amount of fertiliser to apply depends upon the kind of soil, the value of the land, the kind of crop, the market value of the crop, the amount of manure available, whether green-manuring has been practised, the system of farming, and many other factors. No general statement can be made that is of any value. Perhaps a general average for staple crops on the poorer soils of the Eastern States is 20 pounds of nitrogen, 80 pounds of potash, and 100 pounds of available phosphoric acid. Be especially chary in the application of nitrogen. One hundred pounds per acre of nitrate of soda is usually sufficient if used alone. If used with the mineral plant foods, this application may be doubled or trebled.

WHEN IT WILL PAY TO USE FERTILISERS

This depends not only upon the condition and needs of the soil, but also upon the money value of the crop and the value of the land. The higher the value of the land or the crop the more will it pay to fertilise liberally, in order to secure maximum yields which will pay interest on the large amount of capital invested. The largest use of commercial fertilisers is made in market gardens and in special crop farming, as the growing of onions, tobacco, and fruit. It might pay to use a ton of commercial fertiliser on an acre of garden vegetables on Long Island when it might not pay to use 500 pounds on an acre of wheat in Ohio, although both soils were equally in need of fertilising. It is a question of economics as well as of crop culture.

It depends also upon the thoroughness of the farming; a good farmer, especially one who tills the soil thoroughly and keeps it in good texture by the use of green manures and animal manures, makes the use of commercial fertilisers pay, but a poor farmer does not. The physical condition of the soil—which the farmer can largely control and modify—has more to do with the profit in using them than any other factor. Many farmers are not securing the profit from fertilisers that they might if their soil was in better texture.

Fertilisers are so easy to get and easy to apply, that there is a tendency to use them hastily, without regard to their content and the needs of the soil; and to use them in much larger quantities than is really necessary. The rational course to pursue is to use them only to supplement farm resources of fertility; and to use them only up to the point where they return the largest ratio of profit for the expenditure.

Certain materials that furnish little if any actual plant food, but exert a very beneficial effect upon the soil, are called "indirect fertilisers" or "amendments." The most common of these are lime and land plaster and, to a very slight extent, salt.

THE BENEFITS OF LIMING

Lime is an important factor in maintaining the fertility of certain farm soils. It is a plant food. If a soil contained no lime, plants would not thrive upon it. Although most soils contain sufficient lime for the needs of the crop, some soils become exhausted of it and it is then needed not as an indirect, but as a direct, fertiliser.

Lime may benefit certain soils by improving their texture. When applied to a light, leachy soil, it makes it more retentive. When applied to a clay, it has the opposite effect; the very fine soil grains are cemented together and consequently the soil is made more porous. The practical effect is that liming a sandy soil makes it less leachy, while liming a stiff clay makes it more crumbly; the condition of both is greatly improved.

A third effect of applying lime to a soil that is deficient in it, is that it makes the plant food in the soil, especially the potash, more soluble.

Much of the potash in our soils is insoluble, being "locked up" in compounds with silica. Lime attacks the silica and sets free the potash. It also prevents the loss of soluble phosphoric acid in the soil. The practical effect of this is that liming may be equivalent to fertilising, for a time. But since lime supplies no potash, phosphoric acid, or nitrogen, the soil is eventually made less productive. This is the basis for the old adage, "Liming makes the father rich and the son poor."

The most important function of lime in modern agriculture is to sweeten sour soils. A soil that contains free acid is "sour," or acid. Such soils, though they may be rich in plant food, usually produce inferior crops; but if this acid is neutralised by adding lime, they become productive. There are thousands of acres of sour soils in the United States, notably in Rhode Island, Massachusetts, New Hampshire, Connecticut, New York, Illinois, Maryland, Virginia, and Alabama. The application of lime to such soils may do more to make them productive than the use of large amounts of commercial fertilisers.

THE SOILS THAT NEED LIMING

Contrary to the popular notion, soils containing a large amount of humus are not more likely to be sour than upland soils. Soils are sour because the rocks from which they were formed were deficient in lime. Sour soils are very apt to have an abundance of sorrel or "sourgrass." When this plant comes into the field and crowds out other plants, it is a fairly reliable indication that lime is needed, although sorrel often grows well on sweet soils.

Practically all farm crops, except watermelon, Hungarian grass, red-top, blackberries, and the lupines, do poorly on a sour soil; these seem to prefer it. Indian corn and rye stand it much better than the other cereals. Clover, alfalfa, beets, and timothy are almost sure to fail on sour soils.

TESTS FOR SOUR SOILS

A simple and fairly reliable method of determining whether a soil is sour, is to test it with blue litmus paper. This can be bought at a drugstore for a few cents. Get several samples of moist soil from different parts of the field, mix them into a paste with water, and insert one end of the litmus. At the end of an hour, if the blue paper has turned red where it came in contact with the paste, probably the soil is sour.

The litmus test will usually show with considerable accuracy whether a soil is badly in need of lime, but soils which are not actually sour may need it. The best way is to apply lime to a strip of soil and compare the growth of crops on this strip with their growth on unlimed parts of the field. In the fertiliser test previously described, use about 200 pounds of lime on the $\frac{1}{20}$-acre plot.

HOW TO SWEETEN SOUR SOILS

A sour soil should be limed at the rate of 1,000 to 4,000 pounds per acre; two tons per acre is about the maximum of application. The lime should be applied broadcast in late fall or early spring. The best form of lime to use is the water-slaked. Put stone lime in heaps on the ground and cover it with moist soil. In a few days the lime will be found powdered and may then be spread. If air-slaked lime is used, the applications should be heavier. If lime is used in seeding to grass, apply it ten to fourteen days before seeding, if possible. It is not usually necessary to lime soils oftener than once in four or five years.

OTHER AMENDMENTS

Land plaster, or gypsum, which is sulphate of lime, has about the same effect upon the soil as common lime. Gypsum was formerly used very largely, especially on clover, Indian corn, and potatoes. It has been observed to increase the yield of clover 20 to 30 per cent.; but after a number of years, this benefit is no longer obtained. Its beneficial effect is due largely to the fact that it makes the potash in the soil more soluble, thus causing an increase in the crop. Land plaster is not now used to any extent except as it occurs as a part of acid phosphate, but in this case it has no value for sweetening the soil. It can be used to great advantage, however, on the floors of cow and horse stables and the roosts of hen houses to prevent the escape of ammonia. It is also useful, in some cases, for treating alkali soils.

Wood ashes are about 35 per cent. lime, and improve the soil in all the ways that lime does. Part of the excellent results commonly secured from the use of wood ashes is due to the value of the ashes for correcting acidity and setting free plant food.

Marl, which is chiefly fossil shells, contains much carbonate of lime and is valuable for dressing land that needs lime. Large areas of land in New Jersey that were formerly unproductive have been made productive by applications of marl. It improves the texture of the soil, sets free plant food and corrects acidity, the same as lime. If a deposit of it is handy, it is certainly worth using.

Salt was once used considerably as a fertiliser, especially on asparagus. It makes the soil more moist and assists decay, but its agricultural value is not equal to its cost, which is $4 to $6 per ton. The potash salt, kainit, is one-third common salt. If salt is needed, buy it in this form, because the price of kainit is based solely upon the amount of potash in it.

APPENDIX

I. ROTATIONS PRACTISED IN DIFFERENT STATES

The following remarks on the crop rotations practised in or recommended for the different states are a summary of correspondence between the author and the various authorities quoted.

ALABAMA

In the cotton states the majority of farmers pay little attention to rotations. Where small grains are grown the following rotation is recommended: First year, corn, with cowpeas planted in May or June between the corn rows. Second year, fall-sown oats or wheat, followed by cowpeas in June. Third year, cotton. The cowpeas after the crop of small grains are usually cut for hay, but may be picked for seed or may be pastured or plowed under in January or February. This can be lengthened into a four-year rotation, in order to put one-half of the arable land of the farm into cotton, by adding cotton as the crop of the fourth year.

Director, Alabama Experiment Station. J. F. Duggar.

ARIZONA

Our soils are still so new to cultivation and so fertile that the need of rotations has not yet been felt. The deficient elements of our soils are nitrogen and humus. At present, and doubtless largely in the future, these are supplied by alfalfa.

Agriculturist, Arizona Agr. Experiment Station. V. A. Clark.

ARKANSAS

Arkansas is both a cotton and fruit state. Land along the rivers is cultivated in corn and cotton without reference to rotation. Throughout the state cowpeas grow well and are usually sown after oats and wheat are harvested, also in the cornfields. Rye is used only for winter pasture. In the orchard belt the usual rotation is corn, wheat, cowpeas; or corn, oats, clover. The rotation of stock farmers is corn (summer), rye (winter), cowpeas or sorghum (forage), wheat (winter and spring). The weak point in the agriculture of this state is the lack of diversified crops.

Professor of Agriculture, University of Arkansas. Geo. A. Cole.

CALIFORNIA

The course of California agriculture hitherto has been to avoid rotation and to keep the land producing that to which it seems adapted, and for which profitable prices could be had, for an indefinite period. Recently the desirability of rotation has become more apparent, especially in connection with sugar beet growing. Our rotations probably will never be like those in the East because it is only occasionally that a certain piece of land is suited to the growth of three different grains. California must devise rotations of her own, as her agriculture advances, and the question will be quite as much what crop will succeed at all, as what crop will be best for the land.

Professor of Agriculture, University of California. E. J. WICKSON.

COLORADO

Under ditch the principal rotation is alfalfa for several years, beets or potatoes, followed by grain and again seeding to alfalfa. The tendency is to grow beets several seasons on the same ground on account of the high profit of the crop, but they should be grown only one to two years. Where potatoes are grown the same is true. In the San Luis Valley, where 50,000 acres of peas are grown annually, the rotation is peas, potatoes, grain. The regions outside of both potatoes and beets have no definite rotation. We have under experiment a rotation of alfalfa two years, roots one year, grain one year.

Professor of Agronomy, Colorado State Agr. College. W. H. OLIN.

CONNECTICUT

No regular rotation is practised. One of our principal industries is dairying and we must grow large quantities of corn for silo. On fields where corn can be grown with greatest economy it is often the practice to grow corn year after year, using stable manures and commercial fertiliser to maintain the productive power of the soil. A rotation I have found well adapted to our conditions is: First year, corn; second year, potatoes; third year, rye; fourth year, meadow. The rye is put on in the fall after the potatoes are removed, and the grass seeding put on with the rye. Where potatoes are not desired, we sometimes break up the sod and grow corn two years in succession; then seed down either with rye or use grass and clover seeds alone.

Director, Storrs Agr. Experiment Station. L. A. CLINTON.

DELAWARE

On most of the soils of Delaware devoted to grain farming, the most common rotation, and probably the best, is corn seeded to wheat the same fall; the wheat cut in June, the stubble clover and weeds cut once or twice with mowing machine and allowed to fall to the ground; clover, or clover and timothy the next June followed by a second crop of hay; or, more usually, the field is turned out to pasture for the remainder of the year. In other words, a three-year rotation of corn, wheat and clover. Sometimes the field is pastured the second season, making a four-year rotation of corn, wheat, clover, pasture. This rotation in itself is not so good as the three-year rotation, but it means more live stock and, therefore, more forage and grain fed on the farm and consequently more manure. A few farmers get a good crop of corn fully matured every fall following a good crop of crimson clover hay from the same land.

Sec. of Delaware State Board of Agriculture. WESLEY WEBB.

FLORIDA

There is little or no systematic rotation practised. In the northern part of the state, where corn and cotton are grown, they follow corn with cotton and sow cowpeas in the corn, or a row of peanuts between the rows of corn. Farther south where velvet beans are grown and used for fattening cattle a rotation is: corn the first year, velvet beans the second year, and the velvet beans are pastured off during winter and the ground is again put in corn. In the vegetable section of the state, no rotation is practised unless it is forced by plant diseases which can be killed only by rotation.

Professor of Agriculture, University of Florida. CHAS. M. CONNER.

IDAHO

There is little systematic rotation of crops here. A few farmers rotate grain with such crops as corn, potatoes, and beans. In some irrigated sections grain is rotated with sugar beets. In older irrigated sections an effort is being made now to rotate grain with alfalfa. Our practice at the Station is a five-year rotation: Two years of grass, one of corn, one of wheat, and one of oats or barley.

Director, Idaho Agr. Experiment Station. H. T. FRENCH.

ILLINOIS

Some crop rotations which are being practised to some extent in this state are:

THREE-YEAR ROTATION

First year, wheat, followed by cowpeas or soy beans as catch crop; second year, corn, with cowpeas or soy beans as catch crop; third year, cowpeas or soy beans (to be followed by wheat). All crops except the wheat should be fed or pastured or used as bedding and all manure returned to the land. If the corn crop is cut and shocked, then a three-year rotation of corn, wheat, and clover is a good one.

FOUR-YEAR ROTATION

First year, corn, with cowpeas or soy beans as catch crop; second year, cowpeas or soy beans; third year, wheat (with clover to be seeded in spring); fourth year, clover.

If well filled, the second crop of clover should be harvested for seed. All other crops, excepting wheat and possibly cowpea or soy bean seed, should be fed and the manure returned to the land.

FIVE-YEAR ROTATION

This may be the same as the four-year rotation except that timothy may be seeded with clover and the land pastured the fifth year.

Professor of Agronomy, University of Illinois. C. G. HOPKINS.

INDIANA

Corn is our principal crop practically all over the state, and forms the basis of every rotation, as it is generally desired to bring in corn as often as possible. The prevailing rotation, whenever any system is followed, is the three-course—

corn, wheat or oats, clover. The four-course—corn, oats, wheat, clover, is more or less used in central Indiana; also corn, wheat or oats, clover and grass two years. In southern Indiana we sometimes find a two-course—wheat and clover rotation. For general purposes we consider the three-course rotation best. Most of our farmers claim that they can get a better stand of clover in wheat than in oats. Occasionally we find a four-course rotation, consisting of corn, corn, small grain, clover.

Agriculturist, Indiana Agr. Experiment Station. A. T. WIANCKO.

IOWA

Corn is the "money-crop" of Iowa and it is desired to raise as many crops of corn as possible. Clover has thus far been found the most satisfactory leguminous crop for a rotation in this state. In the southern part of the state a common rotation is corn two years; wheat one year; clover one year. This may be extended into a five-year rotation by allowing the land to remain in clover and timothy for two years. Another rotation, practised less extensively, is corn one or two years; oats one year; wheat one year; clover and timothy, one or two years. In the northern portion of Iowa, where winter wheat has not been as successfully grown, the rotation most extensively practised is corn two years; oats one year; clover one year. In many cases it is necessary to sow a catch crop of cowpeas in order to include a leguminous crop in this rotation. Winter wheat is superior to oats as a nurse crop for clover, and is being included in rotations wherever it can be successfully grown.

Iowa State College, Dept. of Agr. Extension. A. H. SNYDER.

KANSAS

Less than 10 per cent., and perhaps less than 5 per cent., of Kansas farmers practise rotation of crops. The three main crops are corn, wheat and alfalfa. Many fields can be found in some sections upon which wheat has been grown almost continuously from twenty to thirty years. The same may be said of corn-growing, especially in the eastern part of the state. Alfalfa is often left on the fields for many years. The size of the farms is such that the farmers must resort largely to wheat culture, as it would be impossible to farm them thoroughly with several crops with the small amount of help. In most of the wheat sections the farmers grow some corn, kaffir corn or sorghum, but do not have any definite rotation. Two rotations we are suggesting are: (1) Alfalfa, four years; corn, two years; wheat, one year; and alternating two years of corn with one of wheat for nine years more before seeding again to alfalfa. (2) Grasses and clover, three years; corn, two years; spring grain, one year; wheat with catch crops, one year, repeating the latter three twice before seeding to grass and clover in wheat.

Professor of Agronomy, Kansas Agr. College. A. M. TEN EYCK.

KENTUCKY

There is no very generally adopted rotation, but as the farmers understand the importance of getting humus in the soil, and of using clover or some related plant in order to increase the nitrogen, they generally employ for these purposes, bluegrass, timothy, red clover, cowpeas and soy beans. The cultivated crops alternating with these are hemp, tobacco, corn and wheat.

Botanist, Kentucky Agr. Experiment Station. H. G. Garman.

LOUISIANA

Many sugar planters plant corn and cowpeas after harvesting the last crop of stubble cane, growing a crop of corn and cowpeas one year in three or one year in four. The rice land is sown for two, or sometimes three years, then devoted to cotton or allowed to grow weeds and grass, and then put in rice again. On the prairies of southwestern Louisiana many fields have been devoted to rice for twelve or fourteen years in succession. On a majority of the larger plantations cotton is grown continuously year after year. Corn is practically the only other crop grown so there is little rotation. On the alluvial lands, one year in four or five cotton land is put into corn and cowpeas. In the hill lands a few plant grain or cotton, two years; then corn and cowpeas one year; and sometimes a crop of oats, followed by a crop of cowpeas. A very desirable rotation is oats, cotton and corn, with cowpeas between. The oats are harvested in May and the land put in cowpeas. These are harvested in September or October and the land is fall-plowed and the following year planted in cotton. The cotton is followed with corn, and cowpeas sown in the corn at the last plowing. The corn is gathered in September or early October and the land is plowed and sown to oats. With the addition of a reasonable amount of acid phosphate this builds up the land very perceptibly.

Director, Louisiana Agr. Experiment Station. W. R. Dodson.

MAINE

In many sections of the state no systematic rotation is practised. We have many "patchy farms"; a man will go to the middle of the field, or to one side, and plow a small area and on this plant any crop. In Aroostook County a three-course rotation, consisting of potatoes, oats or wheat, and clover, is followed. On the college farm, we are practising a four or five-year rotation, potatoes, corn, oats, seeding with the oats to grass, and clover, and allowing the land to remain in grass one or two years. This rotation is frequently followed in dairy sections.

Professor of Agronomy, University of Maine. Wm. D. Hurd.

MARYLAND

The principal crop rotations practised in this state are: Southern Maryland (Tobacco section), (1) tobacco, wheat, red clover; (2) tobacco ,wheat, red-top and red clover. Central and eastern Maryland (dairy farming and grain and hay crops), (3) corn, wheat, timothy and clover, timothy; (4) corn, winter barley, timothy and clover, timothy; western Maryland (beef-cattle and grain farming), (5) corn, wheat, clover; (6) corn, oats, wheat, timothy and clover, timothy.

Director, Maryland Agr. Experiment Station. H. J. Patterson.

MASSACHUSETTS

Massachusetts farming is largely devoted to specialties. Fertilisers or manures or both are used very freely and there is less dependence upon rotations than in many other states. Some of the most important money-crops, especially onions and tobacco, are grown year after year on the same land. In some parts of the state a four-course rotation, (1) turnips, barley, clover and oats, is practised, most of the manure being applied to the corn, not to the grass. In parts of the state where dairying is prominent and where the potato is a money-crop, a common rotation is (2) potatoes, one year; corn, two years (the second for ensilage); grass and clover three years. There are several modifications of this rotation. On our light soils the following three rotations are common: (3) Potatoes, winter rye, clover; (4) corn, potatoes, rye, clover; (5) corn, potatoes, rye, grass and clover two years. Succession cropping is practised with much skill and success by our market gardeners.

Director, Massachusetts Agr. Experiment Station. W. P. Brooks.

MICHIGAN

A rotation valued at the college is corn, wheat, oats or barley, clover or clover and timothy, pasture. In most cases we spread manures upon pasture. We seed always with a grain crop. In Wexford County the following rotation is used successfully: Clover, potatoes, wheat; seeding to clover with the wheat. Many farmers believe that it is not possible to secure a good stand of clover or clover and timothy with oats, and therefore grow wheat or barley.

Professor of Agronomy, Michigan Agr. College. Jos. A. Jeffery.

MISSISSIPPI

As a rule our farmers do not practise crop rotation. Our best rotation for the general cotton farmer is: Fall oats, followed by cowpeas; cotton; corn, laid by in cowpeas. The above rotation has for i's principal object the maintenance of soil fertility.

Professor of Agriculture, Mississippi Agr. College. E. R. Lloyd.

MISSOURI

Missouri farmers are just beginning to rotate crops. In north Missouri and part of Missouri the common rotation has been corn for several years, then grass for a few years and back into corn. In the wheat-growing section it has been mostly wheat for several years, then into grass, and back again into wheat; although some of the farmers have practised a rotation of (1) corn, wheat and clover, or clover and timothy. A rotation used in north Missouri is (2) corn, oats, clover or clover and timothy. Farmers are beginning to sow cowpeas to some extent, using (3) corn, cowpeas, wheat, or (4) corn, cowpeas, wheat, clover; or in some cases simply wheat and cowpeas. In southeast Missouri some farmers harvest wheat, turn the land quickly and put in cowpeas, harvest the cowpeas for seed or hay and put the land back into wheat in the fall. Some farmers in northeast Missouri have a rotation of (5) corn, oats, wheat, clover, in some cases following the clover with timothy.

Professor of Agronomy, University of Missouri. M. F. Miller.

MONTANA

But one rotation is followed to any great extent—two years in clover and two years in grain; wheat or oats being usually grown after the second crop of clover, and oats or barley the succeeding year. On dry bench lands above the irrigation ditch a common practice is to summer-fallow one year followed by a grain crop the next. On the watered land, in some sections, summer-fallow is followed by two or three grain crops. In a few instances, peas are followed by two crops of grain. Sometimes this is made peas, potatoes and grain two years. Some are planning the following rotation: Alfalfa, four or five years; wheat, sugar beets, or other cultivated crops, two years; then one or two seasons of grain.

Director, Montana Agr. Experiment Station. F. B. LINFIELD.

NEBRASKA

Crop rotation is not carried out systematically by many Nebraska farmers. Corn is the main crop throughout the eastern third of the state; frequently it is grown continuously on the same field. Recently farmers have begun to realise the necessity for some change on account of the corn root-worm and other difficulties, and it is now quite common to alternate corn with oats. Where anything like a systematic rotation is attempted it generally consists of corn for perhaps two years, followed by oats put in on the corn stubble without plowing, followed by winter wheat drilled in on the plowed oat stubble. In the central part of the state, corn and wheat are alternated by drilling in wheat between the corn rows. In the extreme western part of the state the occasional complete failure of crops takes the place of a rotation so far as its effect on the land is concerned. A rotation at the Nebraska Experiment Station consists of corn two years, oats, wheat, alfalfa, or mixed grasses. If seeded down it is left for four years.

Professor of Agriculture, University of Nebraska. T. L. LYON.

NEVADA

There is no prevailing crop rotation in this state. More often than otherwise two crops of grain follow alfalfa. Potatoes usually follow alfalfa and are followed by grain. The length of time that land is kept in alfalfa depends largely upon the stand. It is seldom less than four years. Some alfalfa fields in the state are twenty years old.

Professor of Agriculture, Nevada State University. GORDON H. TRUE.

NEW HAMPSHIRE

There are only a few farms which contain arable land in large enough fields to practise a definite system of rotation. The fields on many farms remain in grass for twenty-five years, or even longer. The fields on which the sod is poorest are plowed in late summer and either seeded down again at once to grass or planted to corn or potatoes for a year or two, and then seeded to grass. Perhaps the following is the most common rotation: Corn; potatoes; oats, or oats and peas; clover; clover and timothy; timothy. Prof. J. W. Sanborn practises the following eight-year rotation on his upland farm: Corn (for husking and ensilage); oats and peas; clover; potatoes; Hungarian; timothy; timothy; pasture.

Professor of Agriculture, New Hampshire College. T. W. Taylor.

NEW JERSEY

We have a large number of rotations because of the many crops grown. In general farming the rotations are about as follows: (1) Corn, oats, wheat, clover; (2) corn, oats, wheat, clover and timothy mixed, timothy; (3) corn, wheat or rye, clover. In dairy, potato and market garden sections the rotations are: (1) Corn, oats and peas and cowpeas, rye or wheat, clover; (2) corn, wheat, potatoes, clover or timothy or mixed; (3) corn, potatoes, hay; (4) corn, tomatoes, sweet potatoes, white potatoes, clover. This is not a regular rotation, but these are used as conditions seem to warrant.

Director, New Jersey Agr. Experiment Station. E. B. Voorhees.

NEW MEXICO

But little crop rotation is practised in this territory. Alfalfa, in most cases, is grown continuously on the same land. There is but one arrangement of crops that can be classed as a rotation, that is wheat and corn, which are usually grown in alternation.

Assistant in Irrigation, New Mexico College of Agriculture. A. C. Martenbower.

NEW YORK

One of the best rotations where wheat is grown is: Clover, corn or potatoes, oats or barley, wheat with seeding. In this case the hay is usually harvested but one season. A rotation more generally used in the southern tier of counties where wheat is not grown is: Clover and timothy, two or more years, corn or potatoes, oats with seeding. A rotation considerably used in the northwestern part of the state where buckwheat is much grown, is: Buckwheat, oats with seeding, meadow as long as the yield is satisfactory, then buckwheat again. It is generally recognised that buckwheat has peculiar value for mellowing heavy soils. Advantage is sometimes taken of this to improve such soils for potato growing. The meadow is cut, the land immediately plowed and sown to buckwheat. This is followed by potatoes, then oats with seeding. There are a large number of other rotations found on different farms.

Assistant Professor of Agronomy, Cornell University. J. L. Stone.

NORTH CAROLINA

We have found the following a very good three-year rotation for a cotton farmer: First year, (*a*) wheat, oats, or rye, followed by cowpeas, (*b*) cotton followed by rye, (*c*) corn with cowpeas; second year, (*a*) cotton followed by rye, (*b*) corn with cowpeas, (*c*) wheat, oats, or rye, followed by cowpeas; third year, (*a*) corn with cowpeas, (*b*) wheat, oats, or rye followed by cowpeas, (*c*) cotton followed by rye.

The peas are sown after the small grain crops and harvested; the rye in the cotton and the cowpeas in the corn are sown at the last cultivation.

A good four-year rotation for a tobacco farmer is: First year, clover, corn, tobacco, wheat; second year, corn, tobacco, wheat, clover; third year, tobacco, wheat, clover, corn; fourth year, wheat, clover, corn, tobacco.

An excellent rotation for corn on the fine, sandy loam-soil of eastern North Carolina is, corn followed by bur clover. Sow 4 or 5 bushels of clover in bur just before the last plowing of corn. The clover is plowed under in spring and a volunteer crop appears in the fall. Another promising rotation is: Peanuts followed by wheat, wheat followed by cowpeas, corn with cowpeas, cotton.

Director, North Carolina Agr. Experiment Station. B. W. Kilgore.

NORTH DAKOTA

Wheat is our money-crop. It is grown chiefly with a barren summer fallow every fourth or fifth year, and sometimes with a change to barley and millet occasionally, which is quite desirable. The summer fallow exhausts the soil and gives no return that season. In the flax districts, flax and wheat alternate and the two crops are sometimes replaced by barley or millet. A rotation of three wheat and flax crops and one of corn, potatoes, or other cultivated crops is beginning to find favour instead of summer fallow. This gives as good returns as fallow and forces the feeding of more provender to live-stock. North Dakota farmers are now just beginning to grow clover and timothy and to put them into the rotation.

Professor of Agriculture, North Dakota Agr. College. J. H. Sheppard.

OHIO

The most common rotation in this state is corn, wheat, and a timothy and clover mixture, with a variation in the number of years given to each crop. In some parts of the state a very common rotation is corn, two years; wheat, one year; timothy and clover, three years. In some localities where wheat is not profitable oats are substituted for it in this rotation. Alfalfa is now being used considerably in place of the timothy and clover mixture of the above rotation. Potatoes, wheat, and clover have been found a very satisfactory rotation by our Experiment Station.

Professor of Agronomy, Ohio State University. A. G. McCall.

OKLAHOMA

No well-defined systems of rotation have been adopted in this new country. When this state was first opened, the one-crop system prevailed: wheat, Indian corn, and cotton. Gradually other crops have been introduced; we have now reached a point where rotations can be adopted. The following general rotation could be used in northern and eastern Oklahoma: Corn; cowpeas seeded at time corn is laid by; oats, followed by cowpeas for green manure; Kaffir corn; cowpeas, harvested; fall wheat, followed by cowpeas for green manure. This general plan could be followed in other sections of the state but it would be necessary to substitute other crops, as broom corn in the northwestern counties, and cotton in the southern counties.

Agronomist, Oklahoma Agr. Exper. Station. L. A. Moorehouse.

OREGON

In the western portion of the state, on farms where general agriculture is practised, the rotation is usually with the cereals and clover or vetch; for instance, wheat, oats, clover for two years, or a crop of winter vetch. In the dairying districts corn is grown in a rotation with clover and cereals. In the Columbia River basin in eastern Oregon, the practice is grain growing exclusively; usually wheat, bare fallow, and wheat again. In sections where the rainfall is greater, some farmers follow wheat with barley, then the bare fallow.

Director, Oregon Agr. Experiment Station. JAMES WITHYCOMBE.

PENNSYLVANIA

Probably corn, oats, wheat, grass, the latter including more or less clover, is the most common rotation. In some parts of the state another year of of grass is added. In the southern part, notably in the Cumberland Valley, the common rotations are: Corn, oats, wheat, wheat, grass; and corn, wheat, wheat, grass. In the tobacco districts various short rotations are practised according to the soil conditions best adapted to the growth of this crop.

Professor of Agriculture, Pennsylvania State College. G. C. WATSON.

RHODE ISLAND

The usual practice is to break up sward land and plant potatoes and corn, sometimes reversing the order of these two, sometimes introducing a crop of millet or oats for another season, and then seeding either with or without winter rye or oats. The land is allowed to continue in grass upon most farms so long as there is anything worth cutting. The following rotations are in progress at the Experiment Station: (1) Oats sown in the spring, with common red clover; clover; potatoes, and winter rye sown after the potatoes are harvested; winter rye cut green and followed by Hubbard squashes; onions. (2) Winter rye; timothy and red top seed sown with rye and common red clover sown on the surface the following March; clover and grass; grass; grass; Indian corn; potatoes. (3) Winter rye; common red clover (seed sown in March of the previous year); potatoes.

Director, Rhode Island Agr. Experiment Station. H. J. WHEELER.

SOUTH CAROLINA

Very little rotation is practised here. The main crops raised are corn and cotton. The bottom lands are usually planted to corn year after year and the uplands planted year after year to cotton. Cotton can be continuously grown on the same land without diminishing the yield provided the seeds are returned on the soil. But the continuous growing of cotton on uplands diminishes the fertility rapidly; chiefly because the clean cultivation that is required for this crop permits the soil to wash badly. We recommend a rotation of corn with cowpeas, and a cover crop of rye; wheat or winter oats; cowpeas, with a rye cover crop; cotton. We have a small section in which tobacco is grown; for this crop we recommend tobacco, with a rye cover crop; corn and cowpeas; oats; cowpeas; rye, with a cover crop; cotton.

Director, South Carolina Agr. Experiment Station. J. N. HARPER.

SOUTH DAKOTA

No very definite methods of rotating crops have yet been adopted. In the dryer central and western portions of the state it is important, if not essential, that small-grain crops be alternated with cultivated crops or with summer fallow handled to conserve moisture. In the eastern and southeastern portions of the state, where moisture is more plentiful, a sod crop is needed in the rotation. Some suggested rotations are: (1) Wheat, brome hay three years, flax, wheat, corn. (2) Barley, millet, wheat. (3) wheat, corn, oats. (4) Wheat, corn (manured), wheat, oats. (5) Wheat, oats, corn, flax, millet.

Agronomist, South Dakota Agr. Experiment Station. J. S. Cole.

TENNESSEE

A rotation often followed is corn, alone or with cowpeas, wheat, grass or grass and clover. This rotation is adapted to east and middle Tennessee, and parts of west Tennessee. Short rotations of wheat and clover, and of wheat and cowpeas are also practised to advantage. A good rotation for cotton is: Cotton; corn, and peas; a cereal (usually oats); cowpeas. Two desirable pasture rotations for sheep and hogs are; (1) Barley, (sown in August); sorghum; rape; cowpeas. (2) Clover, either red or alsike, sown in August or early in September; rape or barley or spring oats, followed by soy beans or cowpeas.

Professor of Agronomy, University of Tennessee. Chas. A. Mooers.

TEXAS

The common rotation in this state is corn and cotton. In a considerable portion of the state, notably the black-land section, alfalfa and cowpeas are added to this rotation. We have no grass crops that can come into our rotations; therefore, for the most part, our soils are covered with intertillage crops. In some sections peanuts are grown, in other sections potatoes have a place. Nearly all the legumes are grown with considerable success. In the north Texas black-land country is a four-course rotation of corn, wheat, oats, and cotton.

Professor of Agriculture, Texas Agr. College. F. S. Johnston.

UTAH

There is little systematic rotation of crops, largely because our soil is still nearly virgin. Among sugar-beet growers a common rotation is: Beets, manure applied in the fall and plowed; beets; alfalfa, with oats for a nurse crop; alfalfa, third crop plowed under as a green manure; beets. Sometimes an oat crop follows alfalfa previous to seeding the beets. A better rotation is: Sugar beets, manure applied in the fall and plowed under; beets; field peas with or without oats; sugar beets; corn or potatoes; alfalfa and oats; alfalfa, with third crop plowed under; sugar beets. Where it is desired to grow such crops as tomatoes and possibly wheat, or any other main crops, they can be supplied in place of oats, potatoes, or sugar beets, in this rotation. In dry farming the usual method at present is to grow wheat two years out of three, the land being summer-fallowed one year in three. Occasionally wheat is followed by barley or oats. A better system is: Wheat, potatoes if possible, or corn; wheat; field peas; barley; summer fallow; wheat.

Agronomist, Utah Agr. Experiment Station. W. M. Jardine.

VERMONT

Corn, potatoes, grass; or corn, oats, grass are about the only rotations practised in this state, grass occupying the major time.

Director, Vermont Agr. Experiment Station. J. L. Hills.

VIRGINIA

The most common rotation is corn, one year; wheat, two years; grass for three to five years. Two years of wheat are put in because the farmers do not consider that they get their land in proper condition for grass following the corn with one year of wheat, especially when they expect to mow it for one or two years.

Agronomist, Virginia Agr. Experiment Station. John Fain.

WASHINGTON

There have not been, as yet, any well-defined rotations established. In the extreme eastern part of the Palouse country, there is just beginning to be considerable alfalfa and brome grass grown, but where these are grown the farmers usually put them in for permanent meadow or pasture, rather than inserting them as crops in a rotation.

Through all the wheat belt the common practice is to alternate grain with summer fallow, with two years of grain to one year of summer fallow in the more moist parts of the wheat belt and alternate grain and summer fallow in the drier portions. In the more moist portions the practice is rapidly developing of growing corn, potatoes, or sugar beets on these summer fallows and this is giving excellent results wherever tried. The objections to summer fallowing are too well known to need mention.

In our irrigated sections cropping is becoming highly specialised, alfalfa continuously in one place, hops in another, fruit in another. On the west side of the state specialisation is also marked, though dairying is beginning to be a permanent factor and farmers are seeking to work out some sort of a rotation and some system of soiling. There are no established rotations as yet in the state of Washington.

Assistant Agriculturist, Washington State College. Geo. Severance.

WISCONSIN

In central Wisconsin clover is sown with barley, and the barley harvested; the second year the clover is clipped after reaching the height of about six inches and the full crop retained for seed; the third year the land is plowed and run to corn, followed with clover sown with barley. The most common rotation is clover and timothy sown with barley, oats, or wheat as a nurse crop. First year, harvest the grain. The next year the crop is clover largely, getting as a rule two cuttings. The ground is then manured quite heavily in the fall and winter. As a rule some clover and a good crop of timothy will be secured the third year. As soon as the hay is cut the land is usually pastured until fall. The fourth year the sod is turned and corn planted. Some farmers add a fifth year in which the ground is pastured.

Agronomist, Wisconsin Agr. Experiment Station. R. A. Moore.

WYOMING

There are no crop rotations in general use. In the older farming districts the farmers are generally adopting the rotation common in northern Colorado; namely, alfalfa three years, potatoes, grain and seed down to alfalfa. This rotation is probably unexcelled for the arid regions where potatoes are successfully raised as a general crop. At higher altitudes an excellent rotation is field peas one or two years (to be fed lambs through the winter and not harvested), followed by grain. Farming without irrigation consists in fallow one year and grain or some other crop the next. Our soils are rich in mineral foods and poor in nitrogen and humus, so any successful rotation must contain a legume.

Director, Wyoming Agr. Experiment Station. B. C. Buffum.

II. ANALYSES OF SOILS

The following analyses of a few representative soils illustrate the general composition of farm soils.

ANALYSIS OF ADOBE SOIL FROM SANTA FE, NEW MEXICO

	Per Cent.
Silica	66.69
Alumina	14.16
Ferric oxide	4.38
Manganese oxide	0.09
Lime	2.49
Magnesia	1.28
Potash	1.21
Soda	0.57
Carbonic acid	0.77
Phosphoric acid	0.29
Sulphuric anhydride	0.41
Chlorine	0.34
Water	4.94
Organic matter	2.00

ANALYSIS OF LOESS FROM DUBUQUE, IOWA

	Per Cent.
Silica	72.68
Alumina	12.03
Iron sesquioxide	3.53
Iron protoxide	0.96
Titanum oxide	0.72
Phosphoric anhydride	0.23
Manganese oxide	0.06
Lime	1.59
Magnesia	1.11
Soda	1.63
Potash	2.13
Water	2.50
Carbon dioxide	0.39
Sulphurous anhydride	0.51
Carbon	0.09

ANALYSIS OF SOIL FROM YAKIMA COUNTY, WASHINGTON

		Per Cent.
Insoluble matter	71.67	76.78
Soluble silica	5.11	
Potash		1.07
Soda		0.35
Lime		2.00
Magnesia		1.34
Brown oxide of manganese		0.04
Peroxide of iron		6.88
Alumina		7.91
Phosphoric acid		0.13
Sulphuric acid		0.02
Water and organic matter		2.82
Total		99.33
Humus		4.10
Hygroscopic moisture		4.98

ANALYSIS OF SWAMP SOIL IN CARTERET COUNTY, NORTH CAROLINA

	Per Cent.
Silica (insoluble)	1.52
Silica (soluble)	0.00
Alumina	0.39
Oxide of iron	0.15
Lime	0.36
Magnesia	0.14
Potash	0.06
Soda	0.13
Phosphoric acid	0.06
Sulphuric acid	0.38
Chlorine	0.02
Organic matter	87.25
Water	9.60

III. NATIVE PLANT FOOD IN FARM SOILS

The analyses given below show the large amounts of plant food that are in most farm soils, and the wide variation in these amounts.

Where from	Nitrogen Per Cent.	Phosphoric Acid Per Cent.	Potash Per Cent.	Pounds of Nitrogen in First 8 in. of Soil	Pounds of Phosphoric Acid in First 8 in. of Soil	Pounds of Potash in First 8 in. of Soil
Alabama	.195	.196	.183	4,218	4,240	3,959
Alabama	.282	.267	.866	6,436	6,094	19,756
Canada	.048	.14	.25	1,112	3,244	5,793
Canada	.114	.13	.39	2,638	3,008	9,024
Colorado	.04	.23	.23	872	5,016	5,016
Connecticut	.334	.038	.056	7,224	822	1,211
Connecticut	.14	.051	.047	2,971	1,082	997
Michigan	.11	.28	1.95	2,455	6,250	43,526
Michigan	.07	.21	1.1	1,484	4,451	23,314
Missouri	.14	.08	1.32	3,012	1,721	28,395
Missouri	.13	.07	2.54	2,814	1,515	54,986
Nebraska	.07	1.42	.197	1,530	31,062	4,306
Nebraska	.073	.062	.741	1,581	1,334	15,938
New York	.204	.115	.96	4,362	2,460	20,532
New York	.13	.16	.51	3,074	3,784	12,063

IV. PLANT FOOD DRAWN FROM THE SOIL BY AVERAGE YIELDS OF DIFFERENT CROPS

(The analyses given in IV, V, VI, and VII are chiefly from New York, New Jersey, Massachusetts, and Connecticut Experiment Station Reports.)

Name of Crop	Nitrogen	Phosphoric Acid	Potash
Alfalfa	289	65	181
Barley	78	35	62
Buckwheat	63	40	17
Cabbage	213	125	514
Cauliflower	202	76	265
Carrot	166	65	190
Clover, red	171	46	154
Clover, scarlet	95	17	57
Clover, white	89	29	58
Cowpea	254	64	169
Corn	146	69	174
Cotton	110	32	35
Cucumber	142	94	193
Hop	200	54	127
Hemp	...	34	54
Lettuce	41	17	72
Meadow hay	166	53	201
Oat	89	35	96
Onion	96	49	96
Pea	153	39	69
Potato	119	55	192
Rape	154	79	124
Rice	39	24	45
Rye	87	44	76
Soja (Soy) bean	297	62	87
Sugar cane	518	37	107
Sorghum	446	90	561
Sugar beet	95	44	200
Tobacco	127	32	148
Turnip	187	74	426
Vetch	149	35	113
Wheat	111	45	58

V. ANALYSES OF COMMERCIAL FERTILISING MATERIALS

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid: Available Per Cent.	Phosphoric Acid: Insoluble Per Cent.	Phosphoric Acid: Total Per Cent.
Phosphoric Acid Fertilisers						
Apatite	....	....	....	....	....	36.08
Bone ash	7.00	....	....	....	....	35.89
Bone-black	4.60	....	....	....	....	28.28
Bone-black (dissolved)	....	....	....	16.70	0.30	17.00
Bone meal	7.47	4.12	....	8.28	15.22	23.50
Bone meal (from glue factory)	....	1.70	....	....	....	29.90
Bone meal (dissolved)	....	2.60	....	13.53	4.07	17.60
Caribbean guano	....	....	....	....	....	18.90
Cuban guano	24.27	1.67	....	....	....	13.35
Mona Island guano	12.52	0.76	....	7.55	14.33	21.88
Nevassa phosphate	7.60	....	....	....	....	34.27
Orchilla guano	7.31	....	....	....	....	26.77
Peruvian guano	14.81	7.85	2.61	8.36	6.90	15.26
S. Carolina rock (ground)	1.50	....	....	0.60	27.43	28.03
S. Carolina rock (floats)	....	....	....	....	....	27.20
S. Carolina rock (dissolved)	....	....	....	11.60	3.60	15.20
Florida rock phosphate	....	....	....	....	35.00	35.00
Potash Fertilisers						
Cottonseed hull ashes	7.33	....	23.80	....	....	8.50
Kainit	3.20	....	13.54	....	....	....
Muriate of potash	2.00	....	50.46	....	....	....
Nitrate of potash	1.93	13.09	45.19	....	....	....
Spent tan-bark ashes	6.31	....	2.02	....	....	1.61
Sulphate potash (high-grade)	1.25	....	51.60	....	....	....
Sulphate potash and magnesia	4.75	....	23.50	....	....	....
Sylvanite	7.25	....	16.65	....	....	....
Tobacco stems	10.61	2.29	6.44	....	....	0.60
Wood ashes (unleached)	9.00	....	5.50	....	....	1.85
Wood ashes (leached)	....	....	1.10	....	....	1.40
Nitrogen Fertilisers						
Castor pomace	9.98	5.56	1.12	....	....	2.16
Cottonseed meal	6.86	6.66	1.62	....	....	1.45
Dried blood	12.50	10.52	....	....	....	1.91
Dried fish	12.75	7.25	0.45	3.05	5.20	8.25
Horn and hoof waste	10.17	13.25	....	....	....	1.83
Lobster shells	7.27	4.50	....	....	....	3.52
Meat scrap	12.09	10.44	....	....	....	2.07
Malt sprouts	7.40	4.04	2.20	....	....	1.70
Nitrate of soda	1.25	15.75	....	....	....	....
Nitrate-cake	6.00	2.30	0.40	....	....	....
Oleomargarine refuse	8.54	12.12	....	....	....	0.88

V. Analyses of Commercial Fertilising Materials—*Continued*

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid		
				Available Per Cent.	Insoluble Per Cent.	Total Per Cent.
Nitrogen Fertilisers						
Sulphate of ammonia	1.00	20.50	....	....	....	....
Tankage	13.20	6.82	....	5.02	6.23	11.25
Wool waste	9.27	5.64	1.30	....	....	0.29
Miscellaneous Materials						
Ashes (anthracite coal)	....	....	0.10	....	....	0.10
Ashes (bituminous coal)	....	....	0.40	....	....	0.40
Ashes (corn-cob)	....	....	23.20	....	....	....
Ashes (lime-kiln)	15.45	....	0.86	....	....	1.18
Ashes (peat and bog)	5.20	....	0.70	....	....	0.50
Gas lime	4.40	0.30	....	....	....	....
Marl (Massachusetts)	18.18	....	....	....	....	1.05
Marl (North Carolina)	1.50	....	0.04	....	....	0.56
Muck (fresh)	76.20	0.30	....	....	....	....
Peat	61.50	0.75	....	....	....	....
Pine needles	7.80	0.30	0.10	....	....	0.20
Shell lime (oyster shell)	19.50	....	0.04	....	....	0.20
Soot	5.54	....	1.83	....	....	....
Spent tan bark	14.00	0.20	0.10	....	....	0.04
Spent sumach	30.80	1.00	0.30	....	....	0.10
Sugar-house scum	50.20	2.10	....	....	....	....

VI. ANALYSES OF FARM MANURES

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid Per Cent.
Cattle (solid fresh excrement)	....	0.29	0.10	0.17
Cattle (fresh urine)	....	0.58	0.49	....
Hen manure (fresh)	....	1.63	0.85	1.54
Horse (solid fresh excrement)	....	0.44	0.35	0.17
Horse (fresh urine)	....	1.55	1.50	....
Poudrette (night soil)	....	0.80	0.30	1.40
Sheep (solid fresh excrement)	....	0.55	0.15	0.31
Sheep (fresh urine)	....	1.95	2.26	0.01
Stable manure (mixed)	73.27	0.50	0.60	0.30
Swine (solid fresh excrement)	....	0.60	0.13	0.41
Swine (fresh urine)	....	0.43	0.83	0.07

VII. FERTILISING MATERIALS IN FARM PRODUCTS

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid Per Cent.
Hay and Dry Fodders				
Alfalfa	6.26	2.07	1.46	0.53
Carrot tops (dry)	9.76	3.13	4.88	0.61
Clover (alsike)	9.93	2.33	2.01	0.70
Clover (crimson)	16.4	1.95	1.17	.36
Clover (mammoth red)	11.41	2.23	1.22	0.55
Clover (medium red)	10.72	2.09	2.20	0.44
Clover (white)	....	2.75	1.81	0.52
Corn fodder	....	1.80	0.76	0.51
Corn stover	28.24	1.12	1.32	0.30
Cowpea vines	9.00	1.64	0.91	0.53
Hungarian grass (brome)	7.15	1.16	1.28	0.35
Italian rye-grass	8.29	1.15	0.99	0.55
June grass	....	1.05	1.46	0.37
Meadow fescue	9.79	0.94	2.01	0.34
Meadow foxtail	....	1.54	2.19	0.44
Millet (common)	9.75	1.28	1.69	0.49
Mixed grasses	11.26	1.37	1.54	0.35
Orchard grass	8.84	1.31	1.88	0.41
Perennial rye-grass	9.13	1.23	1.55	0.56
Red-top	7.71	1.15	1.02	0.36
Salt hay	5.36	1.18	0.72	0.25
Serradella	7.39	2.70	0.65	0.78
Soja (Soy) bean	6.30	2.32	1.08	0.67
Tall meadow oat grass	....	1.16	1.72	0.32
Timothy hay	7.52	1.26	1.53	0.46
Vetch and oats	11.98	1.37	0.90	0.53
Yellow trefoil	....	2.14	0.98	0.43
Green Fodders				
Alfalfa	75.30	0.72	0.45	0.15
Clover (crimson)	8.15	.43	.26	.08
Clover (red)	80.00	0.53	0.46	0.13
Clover (white)	81.00	0.56	0.24	0.20
Corn fodder	72.64	0.56	0.62	0.28
Corn fodder (ensilage)	71.60	0.36	0.33	0.14
Cowpea vines	78.81	0.27	0.31	0.98
Horse bean	74.71	0.68	1.37	0.33
Meadow grass (in flower)	70.00	0.44	0.60	0.15
Millet	62.58	0.61	0.41	0.19
Oats	83.36	0.49	0.38	0.13
Peas	81.50	0.50	0.56	0.18
Rye grass	70.00	0.57	0.53	0.17
Serradella	82.59	0.41	0.42	0.14

VII. FERTILISING MATERIALS IN FARM PRODUCTS—*Continued*

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid Per Cent.
Green Fodder				
Sorghum	....	0.40	0.32	0.08
Vetch and oats	86.11	0.24	0.79	0.09
White lupine	85.35	0.44	1.73	0.35
Young grass	80.00	0.50	1.16	0.22
Straw, Chaff, Leaves, etc.				
Barley chaff	13.08	1.01	0.99	0.27
Barley straw	13.25	0.72	1.16	0.15
Beech leaves (autumn)	15.00	0.80	0.36	0.24
Buckwheat straw	16.00	1.30	2.41	0.61
Corn cobs	12.09	0.50	0.60	0.06
Corn hulls	11.50	0.23	0.24	0.02
Oak leaves	15.00	0.80	0.15	0.34
Oat chaff	14.30	0.64	1.04	0.20
Oat straw	28.70	0.29	0.88	0.11
Pea shells	16.65	1.36	1.38	0.55
Pea straw (cut in bloom)	....	2.29	2.32	0.68
Pea straw (ripe)	....	1.04	1.01	0.35
Potato stalks and leaves	77.00	0.49	0.07	0.06
Rye straw	15.40	0.24	0.76	0.19
Sugar beet stalks and leaves	92.65	0.35	0.16	0.07
Turnip stalks and leaves	89.80	0.30	0.24	0.13
Wheat chaff (spring)	14.80	0.91	0.42	0.25
Wheat chaff (winter)	10.50	1.01	0.14	0.19
Wheat straw (spring)	15.00	0.54	0.44	0.18
Wheat straw (winter)	10.36	0.82	0.32	0.11
Roots and Tubers				
Beets (red)	87.73	0.24	0.44	0.09
Beets (sugar)	84.65	0.25	0.29	0.08
Beets (yellow fodder)	90.60	0.19	0.46	0.09
Carrots	90.02	0.14	0.54	0.10
Mangels	87.29	0.19	0.38	0.09
Potatoes	79.75	0.21	0.29	0.07
Rutabagas	87.82	0.21	0.50	0.13
Turnips	87.20	0.22	0.41	0.12
Grains and Seeds				
Barley	15.42	2.06	0.73	0.95
Beans	....	4.10	1.20	1.16
Buckwheat	14.10	1.44	0.21	0.44
Corn kernels	10.88	1.82	0.40	0.70
Corn kernels and cobs (cob meal)	10.00	1.46	0.44	0.60
Hemp seed	12.20	2.62	0.97	1.75
Linseed	11.80	3.20	1.04	1.30

VII. Fertilising Materials in Farm Products—*Continued*

Name of Substance	Moisture Per Cent.	Nitrogen Per Cent.	Potash Per Cent.	Phosphoric Acid Per Cent.
Grains and Seeds				
Lupines	13.80	5.52	1.14	0.87
Millet	13.00	2.40	0.47	0.91
Oats	20.80	1.75	0.41	0.48
Peas	19.10	4.26	1.23	1.26
Rye	14.90	1.76	0.54	0.82
Soja (Soy) beans	18.33	5.30	1.99	1.87
Sorghum	14.00	1.48	0.42	0.81
Wheat, spring	14.75	2.36	0.61	0.89
Wheat, winter	15.40	2.83	0.50	0.68
Flour and Meal				
Corn meal	13.52	2.05	0.44	0.71
Ground barley	13.43	1.55	0.34	0.66
Hominy feed	8.93	1.63	0.49	0.98
Pea meal	8.85	3.08	0.99	0.82
Rye flour	14.20	1.68	0.65	0.85
Wheat flour	9.83	2.21	0.54	0.57
By-products and refuse				
Apple pomace	80.50	0.23	0.13	0.02
Cotton hulls	10.63	0.75	1.08	0.18
Cottonseed meal	....	6.52	1.89	2.78
Glucose refuse	8.10	2.62	0.15	0.29
Gluten meal	8.53	5.43	0.05	0.43
Hop refuse	8.98	0.98	0.11	0.20
Linseed cake (new process)	6.12	5.40	1.16	1.42
Linseed cake (old process)	7.79	6.02	1.16	1.65
Malt sprouts	10.28	3.67	1.60	1.40
Oat bran	8.19	2.25	0.66	1.11
Rye middlings	12.54	1.84	0.81	1.26
Spent brewer's grains (dry)	6.98	3.05	1.55	1.26
Spent brewer's grains (wet)	75.01	0.89	0.05	0.31
Wheat bran	11.01	2.88	1.62	2.87
Wheat middlings	9.18	2.63	0.63	0.95
Dairy Products				
Milk	87.20	0.58	0.17	0.30
Cream	68.80	0.58	0.09	0.15
Skim milk	90.20	0.58	0.19	0.34
Butter	13.60	0.12	....	....
Butter-milk	90.10	0.64	0.09	0.15
Cheese (from unskimmed milk)	38.00	4.05	0.29	0.80
Cheese (from half-skimmed milk)	39.80	4.75	0.29	0.80
Cheese (from skimmed milk)	46.00	5.45	0.20	0.80

VIII. SCHEDULE FOR THE VALUATION OF FERTILISERS

The following is the schedule of prices adopted by agreement by the Experiment Stations of the states of Connecticut, Massachusetts, New Jersey, and Rhode Island, to be used in the valuation of fertilisers for the year 1906:

	Cents per pound
Nitrogen in ammonium salts	17.5
Nitrogen in nitrates	16.5
Organic nitrogen in dry and fine-ground fish, meat, and blood, and in mixed fertilisers	18.5
Organic nitrogen in fine bone and tankage	18.0
Organic nitrogen in coarse bone and tankage	13.0
Phosphoric acid, soluble in water	4.5
Phosphoric acid, soluble in ammonium citrate	4.0
Phosphoric acid in fine-ground fish, bone, and tankage	4.0
Phosphoric acid in coarse fish, bone, and tankage	3.0
Phosphoric acid in mixed fertilisers, if insoluble in water and in ammonium citrate	2.0
Phosphoric acid in cottonseed meal, castor pomace, and wood ashes	4.0
Potash in high-grade sulphate, and in forms free from muriate (or chlorids)	5.0
Potash as muriate	$4\frac{1}{4}$

INDEX