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plowman's folly

BY EDWARD H. FAULKNER

"God's in his heaven—
All's right with the world."
--BROWNING

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to my late father, JOHN WESLEY FAULKNER, JR.
who did for the land as regular routine

much of what farmers now are paid to do as compensation for past errors

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E. H.F.

The Chapters

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THE MARGIN OF ERROR

BRIEFLY, this book sets out to show that the moldboard plow which is in use on farms throughout the civilized world, is the least satisfactory implement for the preparation of land for the production of crops. This sounds like a paradox, perhaps, in view of the fact that for nearly a century there has been a science of agriculture, and that agricultural scientists almost to a man have used and approved the use of the moldboard plow. Nevertheless, the statement made above is true and capable of proof. Much of the proof, as a matter of fact, has come in left-handed manner from scientists themselves. The truth is that no one has ever advanced a scientific reason for plowing. Many learned teachers have bad embarrassing moments before classes of students demanding to be shown why it would not be better to introduce all organic matter into the surface of the soil than to bury it, as is done by the plow.

The entire body of "reasoning" about the management of the soil has been based upon the axiomatic assumption of the correctness of plowing. But plowing is not correct. Hence, the main premise being untenable, we may rightly question the validity of every popularly accepted theory concerned with the production of any crop, when the land has been plowed in preparation for its growth. That brings virtually all of our soil theories up for critical examination, so, in this book, the whole gamut of theory we have evolved concerning the growing of crops will be brought into focus for examination in the light of the discovery that plowing is wrong.

The discussion will be undertaken in language common to the layman, so far as this is possible, and throughout the text footnotes will be introduced to explain whatever may be perhaps out of range of the thinking of the average reader. The nature of the reasoning upon which this entire study is based makes it unnecessary to resort to any but the simplest of scientific terms. Moreover, there are few ideas which are not common knowledge strange as that may seem. The vast amount of technical language created by scientific agriculture, as a result of an early and fundamental mistake, has produced its own confusions. Indeed, the mistake originally made might justly be called the basis for most, if not all, of the technology connected with present-day agronomy.

An agricultural experiment station has its uses, but these obviously would not have embraced the problem presented in this book, if those who work the soil had not got off to a false start in the matter of plowing. In brief, if a way had been found to mix into the surface of the soil everything that the farmer now plows under, if the implements used in planting and cultivating the crop had been designed to operate in the trashy surface that would have resulted from mixing rough straw, leaves, stalks, stubble, weeds, and briars into the surface--crop production would have been so automatic, so spontaneous that there might not have developed what we now know as agricultural science. Actually, we would scarcely have needed one. From one point of view, we have been creating our own soil problems merely for the doubtful pleasure of solving them. Had we not originally gone contrary to the laws of nature by plowing the land, we would have avoided the problems as well as the expensive and time-consuming efforts to solve them.

That we would also have missed all of the erosion, the sour soils, the mounting floods, the lowering water table, the vanishing wild life, the compact and impervious soil surfaces is scarcely an incidental consideration. We have really had a fling at scientific agriculture. The fling, in fact, appears to be the scientific counterpart of what our grandfathers used to call "sowing wild oats." It is time we sobered up and began to apply to the growing of farm crops the same basic science we have for so long been using in the factories, mills, and workshops of our reasonably progressive civilization.

We have equipped our farmers with a greater tonnage of machinery per man than any other nation. Our agricultural population has proceeded to use that machinery to the end of destroying the soil in less time than any other people has been known to do in recorded history. This is hardly a record to be proud of. It gains nothing in attractiveness, moreover, when we consider that our Chinese friends and the often despised peasantry of the so-called backward countries of the world can produce more per acre without machinery than the American farmer can with all his fine equipment. Any reasonably well traveled person will confirm this statement.

One of the persistent puzzles has been the fact that an ignorant, poverty-stricken Egyptian who stirs his land with the ancient crooked stick can produce more per acre than his British neighbor whose equipment is right up to the minute. The explanation is that the poor farmer can't afford the equipment that would make it impossible for him to continue growing such high yields per acre. The full import of all this will be explained in due course.

There is double meaning in the statement that all of the trouble in producing crops seems to lie in the farmer's fields. The uncultivated fields and woodlands surrounding his land do not show any signs of trouble. Even the crops growing in the fence rows seem to thrive through droughts as well as in fine weather. Would that observation justify us in wondering whether the manner in which farmers handle their land might be responsible for the way crops grow under tillage? Certainly we should not overlook the possibility that a clue to the farmer's trouble might be found by a comparative study of cultivated and virgin soils.

Our conventional ideas of growing processes are due for drastic revision. Much thought and experimental work have been devoted to studies of plant growth, but there has been comparatively little consideration of the part played in plant and animal growth by the actual transfer, more or less directly, of previously used plant food from a lifeless body to one that is living.

We often think and speak of growth as if it were a building process--which indeed it is--but we are likely to assume without sufficient thought that the best growth would result from the use of materials not previously used in organic tissues. We think of our farm crops as getting a mineral solution from the land; and we think of that solution as originating from soil minerals directly, or from the fertilizers the farmer applies. We do not give much consideration to the biochemistry of the matter. We know that anything covered up in the soil is subject to rather prompt decay, if it is at all decayable, but we do not reason from that point to acceptance of the decay products as choice building material for crops growing in the immediate vicinity.

In our material civilization we have rightly learned to be suspicious of anything constructed of cast-off materials. Few people would buy an automobile that was assembled from used parts. And a suit of clothes made of shoddy material would not bring a very high price. Our basic distrust carries over into our thinking about the materials essential to lie development of a plant. This would not be true if we did some critical thinking on the subject; but we have not done so. We have left the whole subject to our scientific men. They have learned the facts, and in many instances have published their findings in books or pamphlets which anyone who cares to do so may read; but few have cared to wade through the technical language in which such studies usually have been expressed. Such writings seldom make the headlines or the front pages, so we don't bother to read them. This may be distinctly bad for us.

Much of our knowledge of nutritive relationship is what might be called academic: pigeonholed after discovery and never developed into practical usefulness. Particularly is this true of our knowledge concerning plant nutrition. We know, of course, that no animal can subsist solely on mineral solutions in simple, inorganic form. We do not take our lime as lime water, or our iron as tincture--at least not to any great extent as a matter of nutrition. Our present knowledge indicates that the human race and the whole animal kingdom would disappear completely from the earth if deprived of that organic storehouse known as the plant kingdom. That being true, it is highly important that we have a thoroughly practical understanding of the nutritive relationships between plants and the earth; for those relationships are necessarily fundamental to animal wellbeing, including, of course, the human race.

For purposes of this discussion, it will simplify our reasoning if we think of inorganic solutions, such as those that occur in the soil where water is in contact with mineral crystals, as new, or primary plant foods; and the inorganic solutions that originate in the decay of plant or animal tissues as used, or secondhand plant foods. These are distinctly not the technician's terms for such concepts, but it will be shown herein that they are useful for the layman in understanding how plants may be made to grow best. It should be said, too, that in practice we would almost never find in the soil any organic solution entirely devoid of inorganic compounds. This is because the water which assists in the decay of organic tissues already carries a load of inorganic compounds when it is absorbed into the organic material.

The chief trouble with our farming is that we have concerned ourselves increasingly with the difficult techniques of supplying our farm crops with *new* materials for growth, when we could easily take full advantage of the almost automatic provisions of nature for supplying plants with complete rations in *secondhand* form. We have made a difficult job of what should be an easy one.

Several circumstances have conspired to distort our point of view on the nutrition of plants. Thirty years ago, farmers had not become so familiar as they are now with the possibilities offered by inorganic minerals as fertilizers. But, as they have learned about them, and as the costs of such fertilizers have been reduced from time to time, it has been progressively easier to use mineral fertilizers. Meanwhile the means of restoring organic matter to the soil has seemed at the same time to become progressively more difficult. The net result is that technical attention to the inorganic mineral supply has been more and more necessary, and the organic possibilities have simply vanished from consideration.

The last few paragraphs outline the basic nutritive concepts involved in this book. No new technical discoveries are to be aired here. The discussion is concerned wholly with reducing to practical terms, employable in anybody's back yard or on any farm, the scientific information possessed for decades but hitherto not put to any extensive use.

Green manures have been known and recommended for decades. For those to whom the idea is new, green manures are simply crops of any kind grown for use as decayable material in the soil where grown. Farmers have been advised for years to make frequent and regular use of green manures to supplement the always inadequate supply of animal manure. In keeping with this idea, county agents as early as thirty years ago urged farmers to make the plowing down of green manures the basis of their soil improvement program for very thin land. Then, when the results of those early attempts were reported, trouble loomed. Plowing down great masses of green manure proved such a colossal boomerang that subsequent attempts to improve growing conditions for plants have been cautious expedients rather than bold attempts to imitate the perfect example set by the natural landscape. It seems never to have occurred to anybody to question the effects of the universally approved moldboard plow.

The prevalent and generally accepted doctrine concerning green manures has accordingly been modified to two comparatively ineffective recommendations: (1) plow down the green manure crop early, before it has become woody and difficult to rot, and (2) if the crop gets out of hand and becomes woody before it can be plowed in, apply nitrogenous fertilizers to the crop itself before plowing it down.

Even these recommendations have always been recognized as makeshift procedures. It is only too obvious that tender rye or other green crops must contain less minerals than the same plants would if allowed to reach their full growth. And, while the second recommendation is of more recent origin and is supposed to be more advantageous, it has a fundamental weakness for which there is no completely effective remedy in nature. The purpose of adding the nitrogen fertilizer is to hasten the decomposition of the mass, thus removing the organic matter as a bar to further rise in the soil of water from deep in the earth. (It should be mentioned here that the plowing in of great quantities of absorbent material results in exhausting the water from the overlying soil layers.) The decay is hastened by this trick; but the decay products released are necessarily subject to being leached out of the soil by the first rains that fall after their release. A relatively small percentage of such nutrients can be retained by colloids--in soils which have enough colloids that are not already holding all the plant nutrients possible. The rest must inevitably be lost, unless by lucky chance insufficient rain falls to carry them away before roots arrive to salvage them. It must be remembered, too, that in most soils few roots ever reach the plowsole to do salvage work. The net effect, then, of this treatment is likely to be almost nil.

Later it will be shown that such use of nitrogen--any purchased nitrogen, in fact--is sheer waste of money, since nature is perfectly organized to supply the right amount of nitrogen to every plant. Later, too, the universal use in nature of the principle of direct transfer of organic compounds from the decaying dead to the growing living will be exemplified by illustrations from small-scale test work, supplemented by later field work, done during the past decade in a city back yard and on leased land in the country.

Most scientists probably are mentally unprepared to accept, without official tests, an idea apparently so new. An exception is Paul B. Sears, who in *Deserts on the March* has pictured plant nutrition as follows:

> The face of the earth is a graveyard, and so it has always been. To earth each living thing restores when it dies that which has been borrowed to give form and substance to its brief day in the sun. From earth, in due course, each new living being receives back again a loan of that which sustains life. What is lent by earth has been used by countless generations of plants and animals now dead and will be required by countless others in the future. . . . No plant or animal, nor any sort of either, can establish permanent right of possession to the materials which compose its physical body. *[Deserts on the March*, by Paul B. Sears (Norman, University of Oklahoma Press, 1935)]

Thus, pointedly, Sears brings to our attention a principle of plant growth which has not hitherto been sufficiently utilized, though most scientists have been aware of its academic existence at least. He says by implication that life necessarily depends upon the snuffing out of other lives--of enormous populations, in fact. We dislike thinking of ourselves as murderous, but the fact that we must be, if we are to live, is difficult to refute. As civilized beings, so-called, we keep the slaughterhouse out of sight of the dining room; but, unless we are vegetarians, our very existence depends upon keeping that slaughterhouse busy. Even the strictest vegetarian must snuff out many lives--those of plants--if he is to retain his own.

Such suggestions may sound like bits of philosophical quibbling; however, the ideas involved are so pertinent to the subject in hand that they need to be brought sharply into focus in our thinking. We have always accepted theoretically the interdependence of every form of life upon other forms; we have not so easily progressed to the thought that dead tissues contribute their substance to new living forms. This is the solemn, necessary truth; and the earlier it becomes a part of our thinking, the more quickly can we plan intelligently the necessary work of recreating the soils on our farm lands. We have been too squeamish to visualize dead tissue being transformed into living, though with every mouthful we eat we demonstrate precisely that fact. Let us be practical, even if being so proves painful to our stomachs.

Plants establish intakes, in the form of roots, for nutritive materials in the decaying fragments of last year's plants; and, left to themselves, they will use without loss every atom of the material that previously had been used in the dead plants. As farmers, we have not left the bodies of last year's plants where the roots of this season's crops could invade them. Instead, we have buried those decaying remains so deep that few roots could reach them. We have, by plowing, made it impossible for our farm crops to do their best. Obviously, it seems that the time has arrived for us to look into our methods of soil management, with a view to copying the surface situation we find in forest and field where the plow has not disturbed the soil. No crime is involved in plagiarizing nature's ways. Discovering the underlying principles involved and carrying them over for use on cultivated land violates no patents or copyrights. In fact, all that it is necessary to do--if we want a better agriculture is to recharge the soil surface with materials that will rot. Natural processes will do the rest. The plant kingdom is organized to clothe the earth with greenery, and, wherever man does not disturb it, the entire surface usually is well covered. The task of this book is to show that our soil problems have been to a considerable extent psychological; that, except for our sabotage of nature's design for growth, there is no soil problem.

Science now knows that several times more plant food is carried away from farm land in the streams that drain the various watersheds than is absorbed by growing crops or grazed off by animals. Most of this loss is in invisible form, that is, dissolved--an especially important consideration because it is in the only form in which plants are able to take their food. The undissolved (visible), eroded portion of the loss makes the news, simply because it is visible; but it is relatively unimportant as a loss, since beneath where it lay there is an inexhaustible stock of the same material. The chief damage done by erosion is the filling in of stream channels, reservoirs, and natural lakes, along with the burial of downstream lands under a quite inert layer of miscellaneous mud. Fortunately, the necessary technique for preventing erosion is precisely what is required to make the land most productive. By restoring the conditions which prevailed upon the land when it was new, we will cure erosion and restore productiveness in a single stroke.

For years scientific men have been aware that losses by leaching were in progress, but until the report of the National Resources Board was made in 1934, few had any conception of the staggering scale on which our mineral resources were going out to sea. To arouse general interest in this matter, the U. S. Department of Agriculture included on page 99 of its 1938 *Yearbook* a condensed table of the various kinds of losses. To clarify further the seriousness of our land waste, the department hired Russell Lord, an able agricultural writer, to advertise the government's efforts to stop erosion by co-operative watershed demonstrations in various sections of the country. In his report Mr. Lord gives this concrete resumé of the figures in the report of the National Resources Board:

> Leached plant food is that part that percolates down through the soil and is lost by way of underground waters. . . . Of mineral losses (nitrogen, phosphorus, potash, calcium, magnesium, and sulphur) crops and grazing take off a total of 19,500,000 tons a year, while erosion and leaching whisk away nearly 117,000,000 tons. [No. 321, U. S. Department of Agriculture, *To Hold This Soil,* by Russell Lord (Washington, Government Printing Office), 21.]

Incidentally, Mr. Lord became so impressed by the urgency of the situation reflected above that he wrote *Behold Our Land,* in which he presented further interesting material, and published it the same year.

Most of the dissolved plant food that escapes down the streams originates from the decaying material plowed in. This seems an inescapable conclusion from the known facts. This being true, by salvaging this waste, even though no other measures were taken for soil improvement, we should be able to realize greatly increased production from the land. So long as plant food continues to get away, both land and people become poorer and poorer; and people become more and more subject to ailments which we now know are caused by insufficiency of some essentials in their diets. The drain tile and the moldboard plow, therefore, become suspect of complicity in robbing our people of their birthright of vigorous health--by stealing away vital elements from the plowsole before plant roots are able to salvage them. So logical does this inference seem that it is difficult to under. stand why it has never been investigated officially.

It seems a bit humorous, too, to suggest a need for investigating whether men could grow healthy crops if they copied the soil conditions which prevail in nature where crops are universally healthy. It is a good deal like suggesting to the mother of a new-born baby to investigate the possibility of feeding her child naturally rather than by bottle as conventionally is done. In neither case is experiment necessary. We already know--by incontrovertible example--that wherever man does not interfere crops grow spontaneously. It follows of necessity that if man duplicates in his farming the soil conditions which in nature produce such perfect results, he will be able to grow similarly perfect crops on cultivated land.

So, I introduce to you something so old in agriculture that it may justly be considered as new. The whole thesis is perhaps so clearly obvious that we have universally failed to see it. Seven years were required for me to break away from conventional ways of thinking about soil. Like all others trained in agriculture, I had vainly tried to piece the puzzle together, in order to make of agriculture a consistent science. Then I discovered, through certain tests, that the trouble lay in the operation which preceded all of the tests, namely plowing. It was as if one tried to assemble a picture puzzle with the pieces upside down. By simply correcting the basic error--by incorporating all of the organic matter into the surface of the soil--the difficulties all disappeared as if by magic. The tests by which these conclusions were reached are briefly described in the pages that follow.

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WHAT IS SOIL?

THE WORLD'S first agricultural station was established in England nearly a century ago. At that time its only aims were to learn why England's soils would no longer grow as good crops as formerly, and to discover remedies. Since this beginning, similar institutions have been set up in most of the other countries of the world. There are more than fifty experiment stations in the United States. Some states support more than one, each independent, though all are under the same government. All but a few of these clinics have as a major objective the study of soil problems, and some of them have carried out soil experimental work which shows the effect of given treatments for as long as fifty to seventy-five years.

Such an array of long continued organized effort to determine the facts about the soil makes it seem improbable that we should need to inquire at this late date as to what soil is. Yet, like electricity and a number of other very important and familiar things, the soil has never been adequately defined. Nor is it expected that it will be defined now. It is hoped to arrive in this chapter at a more practical understanding of the soil than we have hitherto had. It certainly is true that, if we could not manage electricity any better than we manage our soil, we could never enjoy the long periods of uninterrupted service that we now do. As it is, we do so completely know how to manage electrical en ergy that it almost never disappoints us. Soil, by contrast, seldom ever comes up to our expectations, even though experts have been trying for generations to solve its problems. It should be remembered, too, that knowledge of electricity is a comparatively modern thing. Edison first made his lamp glow a little more than fifty years ago. Consider what has happened since. Electricity has become the ideal servant of man; it is the only one that obeys an order instantly the order is given. The merest touch of a button or flip of a switch, and your servant is there on the dot. This satisfactory harnessing of electrical energy has been accomplished since the beginning of Edison's experiments.

Compare this amazing progress with the almost complete lack of basic progress in agriculture. Considering that hunger first urged men to activity, we know that man began to cultivate his own food plants as soon as he wearied of the arduous travel and search for them where they grew wild. This happened necessarily quite early in the history of the race. How early, nobody knows, for history could not be written by hungry men, and until a dependable agriculture had been established, hunger at times was inescapable. Soils had been cultivated, worn out, and blown away long before historic times, if we may judge by the tier on tier of buried cities in what now is desert. The establishment of a city anywhere presupposes an abundant food supply near by; so, when archeologists stumble upon the buried ruins of cities built one on top of the other, we know that the local soils at one time supported a considerable population.

You naturally would expect an art as old as agriculture, and as fundamental, to be developed to a fine state of perfection. At least, it would be expected to be far ahead of so recent an art as the use of electricity. Yet the history of agriculture has been a continuous series of disappointments. No race of people ever remained to solve the problems of the area it had worn out. Instead, as fast as the race had harvested the cream of fertility from one area, it sold, or just left, the land to its successors and moved on to richer fields. The following quotation, written at the time of the California Gold Rush, is interesting in this connection:

> Some pains have been taken in this report to prove that one thousand millions of dollars, judiciously expended, will hardly restore the one hundred million acres of partially exhausted lands in the Union to that richness of mould, and strength of fertility for permanent cropping, which they possessed in their primitive state. [Report of the Commissioner of Patents, 1849 {quoted in *The Land*, Vol. I, No. 3 (Summer, 1941), 277}.]

This testifies eloquently to the fact that soil deterioration had made great progress in America nearly one hundred years ago. Many of our best informed experts on soils would agree that, for all our effort of the past generation, we have barely held our own. The average yield of most field crops for any decade that may be selected will not be much larger than the average for the decade of 1870-80. We ought to have done better, surely.

Everybody agrees, of course, that we should have done better; and everybody would be glad to be told how--if anybody knows. The antiquity of our agricultural lore should have been an advantage, but it appears not to have been, because nobody ever actually conquered the problems of the soil he happened to occupy. People instead ran away from those problems and proceeded to create the same problems in a new place. Americans, as a people, did not, therefore, really set out seriously to study the situation until the supply of squatter territory was exhausted. In consequence we have no valuable inherited lore of the soil.

In addition to the advantage of time, the farmer has had another advantage of obvious value which he has never used. He has had before his eyes in every wooded country a perfect example of soil maintenance. And it is said that seeing is believing. Yet, the farmer has seen but he has not believed. He has seen the soft green foliage of the nearby woodland unaffected by the droughts which damaged his crops. He has seen the horseweeds actually topping the fence that surrounded his corn field while his corn was suffering for lack of water. The same weather prevails in the woodland and in the fence rows as prevails in the farmer's fields; yet neither the wild crops of the woodland nor the weeds along the fence show any sign of thirst.

This example of the unplowed field, this evidence that trouble stops where the plow stops, has been almost universally overlooked. Note this masterful description, by an early American, of the untouched forest:

> The soil we passed over this day was very good. Charming valleys bring forth like the land of Egypt. Grass grows as high as a man on horseback and the rivers roll down their waters to the sea as clear as crystal. Happy will be the people destined for so wholesome a situation, where they may live to the fullness of their days with much content and gaiety of heart. [Colonel William Byrd (a Virginia planter) writing in 1728 concerning surveying in the Dan River Valley, Virginia [quoted in *The Land*, Vol. I, No. I {Winter, 1941, 60}.]

Unless cleared, or cut over, the forest continued its lush, rank growth. It was busy making lumber. It was converting into the finest imaginable walnut, gum, oak, cherry, maple, and pine the rotting leaves and other debris that lay on the ground just above the tree roots. In terms of today's living, the lovely woodwork of your floors, stairs, door frames, and in other parts of your house is made largely from reconditioned material--from rotted leaves, rotted wood, and all manner of decayed material. This fact will bear remembering as you read further. It is important.

Almost everyone has had the pleasure of walking through a forest. Did you note uprooted trees? And did you wonder why the roots seemed to bring up chiefly a layer of surface soil? The reason the uprooted tree disturbs only the surface soil is that the feeding roots are necessarily deployed in this zone. The deep roots of the tree provide anchorage against the wind, but it is the tiny, tender feeding roots in the surface layers of soil that do the real business of finding food for the tree. They need not go deep, for the water deep in the soil is brought up to them by capillarity in any case--just as the lampwick brings fuel to the flame. And the food supplied by these roots is chiefly the reconditioned material released when fallen leaves rot on the forest floor. Some new material, dissolved from the rock deeper in the soil, is included, of course; but much the greater part of the minerals used by plants of any kind growing in such an environment must be "secondhand" minerals. It is difficult to believe, when you study the beautiful grains of woods, that they are assembled from "scrap" materials. But in reality that is the way things are done in nature.

This, then, is the shining example of successful soil maintenance which has always been observable by the farmer, if he would do so. Perhaps because it was so near and so obvious, he has been unable to think of it as a lesson from which he should profit. There is more than a little of psychology in the failure of man to profit from the forest's demonstration--or the equally significant showing made by the grasslands which supported myriads of animals and yet gained fertility momentum year by year. To appreciate fully this psychological background will require time, for it involves the underlying reasons that caused plowing to achieve its popularity. Aside from that, there are curious human factors almost inherent in the makeup of man himself.

Not the least of these inherent human traits that have served to perpetuate error in the farming business is the incorrigible feeling on the part of people that they can be of assistance to plants in their growth. The statement appears at variance with our basic thinking, but, actually, there is nothing that anybody can do to assist a plant that is growing in its natural environment. And when we grow plants in an artificial environment, the best we can possibly do is copy as closely as possible the essentials of the natural environment. You know how you swell with pride when you succeed handsomely with your flower or vegetable garden. You imagine you have really helped the plants to grow--and, in a sense, you have. Yet, probably you set them in an unsuitable environment, then proceeded to further sabotage (unconsciously) the natural provisions for the welfare of plants. You are perhaps not peculiar in this respect. Everyone else does essentially the same thing and feels just as proud as you do, in spite of the error of his ways.

The reader will find it difficult, perhaps, to believe some of the facts I am going to recount, for they reveal how truly we humans stand in our own light in attempting to grow plants. What I have to tell, however, is true in all respects and will illustrate adequately my present point.

Some years ago our family spent a holiday foraging the woods for ferns to set in a shaded corner of the house wall. We found ferns, and we found a seedling hemlock actually sitting atop a very flat stone, its roots covered with leaves. There was no connection with the earth. Admiring this tiny tree, I picked it up, literally, since it had no roots in the earth to resist, and brought it home to transplant. Because its root system was a perfectly flat arrangement, I took a spade and patted down a flat area of soil, set the young tree on this spot, covered its roots again with quite a lot of leaves brought in for the purpose, and considered it transplanted. It stands in the same spot today, having grown quite from the start. To my knowledge it has never been supplied artificially with any water, except during one very dry period the first summer. The tree began to show signs of trouble then, so I poured one pail of water about its roots. Since it has become well established, nothing whatever has been done to assist it.

In mid-May or early June, 1941, my wife took a fancy to a maple tree three feet tall which she saw growing in a friend's yard fifty miles from our home. It was in full leaf, of course, so transplanting would present, supposedly, a difficult problem. The friend dug it for us, and we packed it in the trunk of the car. Next morning when we first saw it, its leaves were badly wilted, though still as green as ever. I first set the roots into the pool until a hole could be prepared. This hole was dug in the driest kind of place. There was no sign of moisture even at the bottom of the eighteen-inch space dug out. Because of this extreme dryness, the hole was filled with water. Into this water the tree was then placed, and the dirt removed from the hole was slowly settled about the roots. The work was done slowly in order to avoid causing the water to overflow the sides of the hole. When the hole had been filled in again, the tree was set. Throughout the summer its leaves showed no sign of ill effects from the transplanting experience. I should add that its treatment was not as fair a test as that of the hemlock, for my wife could no resist the temptation to water the maple occasionally. However, it is true that it went through many dry, hot days without being watered.

It has long since become axiomatic among scientists that the data supporting a given statement must not only be accurate but must be extensive enough to eliminate, within reasonable limits, the possibility of error in generalization. My next experiment involved operations on a much larger scale the planting and care of an acre of tomato plants in each of the years 1939 and 1940. More than ten thousand plants were used during the two seasons, and the stand of plants was virtually 100 per cent for each season and each acre field. Soil moisture conditions were quite different for each of the two seasons, but the success of the plants was very similar. The experiment established to my satisfaction, at least, the importance of two principles: first, that the naturally settled, tight condition of the soil (before we start to get it ready for transplanting operations) is desirable; and second, that such soil should not be disturbed if transplanting can be accomplished without disturbing it.

At the outset, the soil was disked thoroughly in order to destroy whatever vegetation was at that time growing on it. In the spring of 1939, there was little but a scattering stand of weeds. In 1940, rye fully three feet tall--a fair stand all over the surface had to be disposed of. The disk harrow so completely mixed in even the rye crop that little sign was left of any vegetation cover. Following the mixing in of this decayable material, the land was marked off in rows. To do this marking, a specially designed implement was used which simply "tramped" over the field--behind the tractor, of course firming the soil together again at points where plants were to be located. By exerting considerable pressure at each such point, this implement reconnected the capillary contacts which the disking had broken up. (To visualize the effect of pressing the soil together again, just recall what would be the effect of snipping the lamp wick above the oil level; then later sewing the pieces together again.) The natural wicking action of the soil--destroyed temporarily by the disking--was restored *in the vertical column of soil just under the point where a plant was to be set.* That this actually was the effect of this pressure we have plenty of evidence. Even though the soil surface was dry and the weather hot in 1939, the bottom of a great many of these "tracks" showed moist even in the middle of the day. Unless the capillary connection had been restored, this could not possibly have been true.

Transplanting was done in the simplest possible manner. The roots of each tomato plant, after being freed of all clinging soil, were laid in the prepared track, covered with as mellow earth as could be found near by, and firmed in place by tramping. No attempt was made to place the plants upright. That is something that nature will attend to. Thus, the plants were left lying flat on the ground; but they did not lie there long. By late afternoon every plant set in the forenoon was pointing its tip toward the sky; by the following morning every plant without exception was standing upright. No water was used in transplanting, or afterward. Capillary water already in the soil was brought in from below--through the compressed column of soil beneath the site where the plant stood--and provided a dependable, continuous supply of moisture. No watering that could have been done at transplanting time could possibly have equalled this inherent natural supply. So, instead of going through a wilting period after transplanting, these plants (even though in some cases they were wilted when set) straightened up and never again, regardless of dry weather, showed signs of trouble from lack of water. And, which is additional proof of the validity of the method, blossoms which were on the plants when set often produced fruit. Any experienced gardener will recognize this as unusual.

In 1940 the entire acre was set in one day by an eleven-year-old boy and me, assisted by my daughter, who removed the plants from the flats for us. Moisture conditions were so different in 1940 that even less care was required, so we cut the work as short as possible. The boy literally dropped and I covered. He placed the plant roots in the proper space; I laid on a hoeful of as mellow earth as I could find in soil so soggy that we barely could walk over it without sinking in. For about five weeks after transplanting, this soil was too wet to be stirred. Several times, indeed, it was flooded. The plants in such wet conditions became purple, or purplish green. Yet, despite this extremely wet condition so long continued, this acre was later spoken of by neighbors as the finest field of tomatoes in the neighborhood. And the plants produced without interruption from the appearance of the first fruit until frost. Some of the very finest fruit was on them when frost came.

This description of the transplanting method used should show conclusively that it pays not to disturb the natural provisions for supplying plants with their needs; and that, if those arrangements must be disturbed, they should be restored to normal before transplanting is done. It was necessary to dispose of the rye that was growing on this land in 1940. Had custom been followed, it would have been plowed in; and in all probability tomatoes could not have been started successfully in it for a long time, if at all. As soon as it was disked in, the plant-setting could have followed immediately behind the marker. However, owing to the danger of late frosts, the actual placing of the plants was delayed until a week later.

In view of the extensive writings available on the proper procedure to be followed in transplanting, the method used with these plants will seem the rankest of carelessness. One of my neighbors thought so in 1939. He is a retired farmer and had learned something of the new theories upon which I was working. In general, he approved the ideas; but, when he saw the strange equipment (the marker) being used and observed the plants being set in so unorthodox a manner, he offered a friendly warning that they would never grow. It was with a broad grin that he came to the field later on, when we were picking the fruit, to say that we had the best stand of plants he had seen all summer.

What he had mistaken for carelessness was instead my full confidence that the soil unassisted would take care of the plants if we did nothing to prevent it. He had always assumed toward transplants (as did everybody else) an attitude similar to that of the broody hen toward her unnatural brood of ducklings. The hen is frightened when the day-old balls of down slide easily into a pool of water. People are similarly astonished to find that plants can get along without the customary care given them by the human race, provided only that they are placed in their proper element. We were trying to put these plants into an exceptionally correct environment. The decaying rye was to be reconstructed into fine red tomatoes; and the necessary water for accomplishing this transformation was to be conducted from below to the roots of the plants, without the customary interruption at the plowsole some six to eight inches under the surface of the soil. (This interruption, something which does not exist in nature, consists of the blotter-like layer of organic matter which the moldboard plow sandwiches in between the subsoil and the disturbed upper layers.) We were copying as closely as possible the natural environment in which plants always seem to thrive; but our behavior was so odd to anyone schooled in the customary ways of managing crops that it became disturbing to observers.

Much more might be said in support of this new conception of soil and the proper handling of it, but the reader will perhaps realize by now that Browning was right.

"God's in his heaven--
All's right with the world."

There is nothing wrong with our soil, except our interference, deliberate though unknowing, with the natural provisions for growing plants. Nothing is more obvious than the vigorous way in which nature takes over when land has been abandoned by farmers. All through the South, farmers have for generations "rested" their land for a number of years between periods of cropping. This practice used to be criticized severely as an evidence of laziness, but agriculturists have discovered that it really has merit, and that soil so treated is considerably rejuvenated and will again produce satisfactory crops. The benefits to be derived from allowing land to lie idle are directly proportionate to the abundance of wild plants that spring up. Southern farmers of the old school never kept their crops so free from weeds that there would not be plenty of seed to germinate on any land that was left to itself for a season or two. The second and third seasons' growth of weeds registered, by their increased height and vigor, the benefit the new plants received from the decaying material produced the previous year. The longer the fields lay idle, the more completely they were restored to normal productiveness. If many years intervened between plantings, however, a young forest might have to be cleared off the land again, so farmers usually renewed cropping after three or four fallow seasons.

Such processes of soil renewal really should not be construed as idleness for the soil. In reality the so-called idle soil is working vigorously to re-establish a non-erosive surface. If there are enough weed seeds in the soil when it is abandoned, only a few years will be required for the surface to be properly "nailed down" again, so that runoff water will not be so plentiful or so effective in moving the soil minerals.

Many of the ills of the soil are those which we humans have induced. We could have avoided all of the trouble we have had with the soil. But that we should have made precisely those mistakes which are now part of history is logical, when it is considered that the plow--now the worst curse of the land--was at the time it was invented a life" saver for the population. The reverential regard we have for it stems from those early days when people escaped the starvation then threatening only because the plow enabled them to handle larger areas of crops. This is more full discussed in Chapter 4. It should be understood, however that, while this book condemns plowing without reservation, it is in no sense an indictment of the men who have recommended it throughout the years. The motives back of such recommendations were as deeply rooted in their natures as are the religious teachings of one's youth. It was my own good fortune to be compelled to make soil where none existed. The solution of this problem pointed unmistakably to the solution of most of our soil problems.

It is safe to say that if the invention of the disk harrow had preceded that of the moldboard plow, and if planting and cultivating equipment had been designed to operate in the trashy surface it would have left, there would never have been a moldboard plow. It should be clear that the immaculately clean material we now have on most of our farms cannot be called soil except by the most liberal literary license. Our ideal of the soil includes of necessity that it must be easy to work, free from obstructions. It must be tidy.

The fact is that untidiness to an extreme a surface covered or filled with abundance of decaying trash--is really the proper condition. We must, therefore, revise our ideas as to the nature of the material upon which we can depend for sustenance. We certainly can not depend upon the almost white soils we now cultivate with the plow.

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SOIL DOES NOT ERODE

IN A VERY IMPORTANT SENSE, soil does not erode, for the more or less pure minerals that are left after all the organic matter has disappeared from the land are not, properly speaking, soil at all. They are merely the raw materials from which soil was originally made and from which it can be made again. Erosion begins only after the soil surface has become virtually non-absorbent--a condition induced by the compactness resulting from the loss of highly absorbent, cellular organic matter present in nearly all undisturbed soils.

In native meadow or forest, rainfall--even the most torrential--strikes the spongy mass of humus and is held, with little or no runoff. Wherever there is runoff, the movement is retarded and ultimately halted by the successive areas of absorbent organic matter over which the water moves. In a tight soil, free from organic matter, erosion is almost inescapable because the very tightness of the soil defeats the gravitational movement of water.

Equally, a soil surface nicely charged with organic matter--decayed vegetable growth, trash, and dead and still living roots of all kinds--is poor field for the forces of wind erosion which have been so destructive in certain western states. But a soil which has been impoverished of organic matter is all too often gone with the wind.

Human generations are too short for us to have actually witnessed the complete cycle from virgin to eroded soil. William Byrd, the Virginia landsman of the eighteenth century, described the portion of this cycle that most people today have never seen. The following account of corn planting by a farmer of the early days is quoted from Ben Ames Williams' *Come Spring:*

> He early cleared a patch of land and planted corn as soon as he had done his burning. The green wood was not consumed by the fire, and charred carcasses of trees lay everywhere; but he did his planting among them, poking a hole in the ground with a sharpened stick, dropping in two or three kernels, brushing earth into the hole with his foot. [From *Come Spring,* by Ben Ames Williams (Boston, Houghton Mifflin Company, 1940), 111.]

By great good fortune, I have witnessed the planting of a number of fields of corn in our own time by much the same method as that given above. Prodigious crops can be produced by such apparently careless methods in such an environment. Two hundred and fifty bushels per acre are an easily possible yield. *Farmers' Bulletin No. 400*, issued by the United States Department of Agriculture but now long out of print, describes a corn yield in South Carolina that measured up 239 bushels per acre. It is certain that even this yield is well within present possibility.

Such highly productive land did not erode. It could not. There was no clean, smooth surface such as we now know. The entire depth of soil, perhaps ten to fifteen inches of it, was filled with visible organic fragments or was stained with the fine black smudge which represents the final stages of organic decay in the soil. This material was highly absorbent, to the last black stain. Such substance would scarcely permit a single drop of an ordinary rain to escape over the surface. There was too much empty space to be filled within the organic matter itself. Indeed, little water drained down through this material until it had taken in all it could hold. The depth of the black zone and the amount of water it already held determined how much additional water could be absorbed. In periods of very heavy rainfall most of the water would go on through this mass, of course. There could be no runoff water, except in long-extended wet periods. Even then the runoff water would not be stained with clay. It would be as clear as crystal--quite different from anything we see today. The surface drainage from cultivated lands in our time is always the color of the land.

It will perhaps be objected that when this mass becomes frozen solid no more water can get into it than can penetrate any other solid mass. This is true--if the mass becomes frozen solid. But it is difficult to freeze such a mass solid enough that water can not penetrate it. There are two very good reasons for this: (1) The water retained by fragments of organic matter is held within the fragments, leaving open spaces between them. Examine a saturated straw pile. There is no water between the straws, though the straws themselves will be full. Even when this water is frozen, there still is plenty of open space throughout the mass. (2) Such a mass of organic matter is so perishable that decay processes are continually in progress, except when there is too little heat or too little moisture. To some extent these fermentation processes provide their own necessary heat. (Remember in this connection that gardeners depend upon the heat of fermenting manure to keep up the temperature of their hot beds.) This ability to maintain higher temperatures, even in wintertime, shortens the period during which a highly organic soil can be frozen.

There are other influences that conspire to prevent tight freezing of a soil that is chiefly organic matter. A covering of snow is the best kind of insulation against the much colder upper air. Soil will often remain unfrozen through a long, cold winter in temperate latitudes, provided it is covered by enough snow. It is well known that snow falling on weeds or any other kind of organic matter is more apt to remain snow than it would if it fell on moist, unfrozen mineral soil. When snow falls on the latter, it immediately dissolves, much as it would if it fell into water; yet at the same time, that which falls on grass, boards, rail fences, roofs, or any other dry substance may accumulate rapidly and remain undissolved. Soil which is highly organic in character, similarly, accumulates snow more readily, because it always presents a drier surface. It is reasonable to believe that throughout the winter it retains a thicker blanket of snow than the pure mineral soil; and with the coming of spring the heat of fermentation within the soil will more quickly thaw out any frozen layer that might exist near the surface. This improves internal conditions for water penetration.

It has long been known that relatively little water escapes from a forest floor as runoff. Just why this is true has been a matter for conjecture, though part of the explanation at least was advanced earlier in this chapter. A commonly held theory is that the organic matter hinders the progress of the water over the surface of the minerals in the soil, thus allowing more time for the minerals to soak it in. Doubtless there is some such effect. It may be more important than I think. It certainly is true that much of the water soaks directly into the leaves and other trash which are found on the ground. And we know that the entry of moisture into leaf tissue is much easier than into mineral soil.

It may not be generally known that when water penetrates mineral masses it does so by finding its way *between* the particles. The tiny particles of clay, silt, or sand are almost completely exclusive. Water can not enter them. It can only cling to their outer surfaces. This is extremely important information to keep in mind in a study of soils, for organic matter, by contrast, literally pulls liquids into itself. Volume for volume, then, organic matter can hold many times as much water as can any kind of soil mineral; for organic matter is chiefly open space internally, while minerals are dense, solid crystal; a fateful distinction where water relations are concerned.

The idea is abroad that man is the lord of creation--that he dominates the earth. In certain minor respects this may be true, but in the main it is the purest propaganda; as ineffectual, when we examine the facts, as whistling in the dark. Consider the single example of erosion. The alarm of thinking men today, when they consider the plight of coming generations starving on eroded soil, borders on panic. What would they think if there were immediate prospects of a renewal of the worldwide erosion which originally sculptured the present features of the earth's surface? That was erosion with a vengeance--millions on millions of years of it. Mountains were buried in the sea by the tearing down of the original fire-formed stone of which they were composed, and the removal of the debris by the unhindered waters and winds which shuttled back and forth across such continents as then existed. Geologists still puzzle over the wreckage, trying to piece out the story.

That original large-scale erosion was finally curbed. But it was not done by that self-advertising animal called man. It was done by vegetation--plants. Plants, the conquerors, had to start from nothing but powdered rock. Some structural materials they extracted from the minerals themselves, some from the air and the rays of the sun, and the rest from water. The porous architecture they were able to create from these materials is still the wonder of existence, though so commonplace as not often to be even an object of curiosity. A casual glance at a bit of onion skin, or a few strands of algae, under a microscope is a revelation to the uninitiated, even though no further thought is given to it. If it is considered that this delicate, lacy network of cells could not be possible except for the presence in infinitesimal amounts of such chemicals as phosphorus, iron, sulphur, calcium, potassium, and magnesium, the miracle of life becomes apparent. To know, then, that world-wide erosion was curbed in the beginning by stuff similar to that on the microscope slide should give us a healthy respect for all plants and for their disintegrating remains; for, down to the last black colloidal remnant of the dead plant or animal tissue, organic nature continues to fight erosion by the trick of absorption. By eternally coaxing water to enter, organic tissues keep it under control. Hence the importance of having the organic tissues where the water can reach them the instant it hits the earth as rain.

Plants are the real masters of the earth. Independent of human management, since they antedated the race, plants came spontaneously from the sea and threw a restraining influence over the unstable surface of the land, quieting its restlessness. Botanists explain the process in detail and with plausible reasoning, allowing eons for the lapse of time from the first single cells to the giant sequoias, and other eons for suitably equipped plants to complete the vegetative mantle over the earth. Moses offers a different story, of course, but be that as it may, we can be sure that man will master the rest of creation only as he comes to terms with plants, the real masters. They hold the key to his food supply.

Admittedly, we have serious erosion to contend with now. Much of our land is again in almost precisely the condition all land was in before plants arrived. It is bare, and it is in movement. Yet the present situation is immeasurably more favorable than the earlier one. The same destructive forces of wind and water are at work now as then, but the forces of plant opposition are now fully organized and mobilized. Alone, unless interfered with by man, plants can reclaim wayward land in an infinitesimal fraction of the time that was required eons ago, before they had adapted themselves to such work. Even so, such a reclamation period, when measured in terms of human lifetimes, may be excessively long. We are likely to get hungry waiting for natural forces alone to stop erosion and restore soil to the eroding mineral surface. Men must lend a helping hand.

The processes by which vegetation accomplishes a new cover where the previous cover has been destroyed are neither secret nor mysterious. All botany texts and a variety of other scientific treatises discuss the influences that determine the development of plant communities. These factors have been so ably discussed elsewhere that there is no necessity for my doing so here. It may be pertinent, however, to introduce some of the underlying principles which determine the nature of plant successions as they occur.

Important among the life factors that occasion the growth of one plant as against another in a given location are the requirements of the species for water and for heat. Although the temperature of the air is influenced to a certain extent by the soil, we may pass it over, because it is not of major concern. Water, being literally managed by the surface upon which it falls, becomes the key factor to be discussed. Moreover, the manner in which the supply of water available for future plants is increased or decreased from year to year as a result of changes wrought by successive generations of plants on the site is an important consideration for us.

The earliest plants to occupy an area are composed of a more or less spongy tissue capable of absorbing and holding water for future need, in addition to that being used currently. This reserve water is supplied to the active plant tissues as required, and saves the plant from extinction when its roots have exhausted the supply of water in the soil. Such are the lichens and mosses. Their remains, unless whisked away by the wind, accumulate from year to year. In a few years the soil itself will necessarily have become intermixed with these spongy remains, so that many times more water will be retained in the soil than could be held by the pure minerals in the beginning This additional water makes the living lichens thrive, which in turn further increase year by year the accumulated sponginess in the soil itself. If there were no other kinds of plants in the world, it is easy to conjecture that these pioneer plants might develop to giant sizes, like the cacti of the desert.

Miles away from this hypothetical spot where the lichen-moss drama has attracted a better water supply, another spot is covered by plants that could not possibly have endured the conditions through which lichens and mosses lived and prospered. As if by magic, seeds of these less hardy plants arrive by wind, bird, or animal. Presently the new plants annihilate the pioneers by the simple procedure of growing taller and robbing them of their essential sunshine. So the plants that prepared the way for these interlopers have to find another bare spot on which to make a new start. Later, the newcomers in their turn are driven away by other kinds even less hardy for which they have paved the way. In this evolution of plant populations on a given spot, the indispensable condition to a thriving community is increasing ability of the soil to retain rainfall.

The availability of water, while a prime consideration, is no more important than other requirements of plant growth; but it may prove the key factor in determining the degree to which a given species is provided with or exposed to other needed conditions. Thus water availability, by developing more expensive tissues, necessarily creates light limitations for low growing plants, so that water, not the unavailability of light, becomes the primary factor in crowding out a species which fails because of lack of light. It would not be surprising to find that the presence or absence of water is the real key to situations supposedly created by other factors.

In any case, each successive stage in the laying down of an absorbent mat on the earth's surface removes one step further the possibility of runoff and erosion. It is not for nothing that writers have referred in literary contexts to "the earth's carpet," for in a very practical sense it is the carpet which covers and protects the landscape. Consider the fallen autumn leaves: snow will billow high upon them in the winter months, melt in the sunshine of spring, and yet the leaves in the center of a heap will be dry. It is the humus below which has profited, as the winter moisture has filtered slowly down, to be caught and held by the sponge of true earth.

Conventional thinking about erosion so far has centered about the idea of securing greater infiltration into the mineral soil, since that is about all that is left on many farms. We have given almost no thought to the idea of providing volumetric space in and on top of the soil into which the rainfall would be helplessly snatched as soon as it fell, thus halting erosion at its source. Two reasons have favored such thinking:

1) It has never been thought possible for planting and cultivation to be done except on a smooth surface. Hence, nobody thought to try or suggest the possibility of growing cultivated crops without first disposing of whatever trash littered the surface. Such trash was always disposed of by plowing.

2) Farmers and scientists have long known that the chief need of soils is organic matter, but that need was supposed to be met by plowing the organic matter into the soil to a depth of six to eight inches. Nobody seemed to realize that this procedure actually robbed the following crop of virtually all the substance of this buried organic matter.

By such hapless reasoning we have preserved for generations a system of soil management which should long ago have been revised to conform to the known facts. Planting can be done in a trashy surface. It had to be done so when the land was first cleared. Doubtless, it is easier to manage land which has nothing on the surface to be caught and dragged along by the sliding equipment we use for planting and cultivating. But, if the crop planted in such smooth land must necessarily produce a smaller yield because of the purity of the minerals (freedom from decaying organic matter), it seems logical to suggest the wisdom of trying to devise implements which will negotiate the trashy surface. Equally, if crop yield is greater from a trashy surface, as has been proved by official tests at the Nebraska Experiment Station, the desirability of the necessary equipment is beyond question.

We emerge with two highly important objectives well within our grasp: improved crop yield, which is immediate, and arrested erosion, which is long range but closely related to our ultimate welfare. Both are attainable by the simple procedure of abandoning the ancient practice of plowing organic matter under and substituting instead the effective practice of leaving the matter on the surface or working it in from the top. The organic sponge on top precludes erosion and provides the substance for maximum plant growth. That which has been plowed under leaves a denuded and tight surface ideally suited to the processes of erosion, while the nutriment for plants lies six to eight inches below their incipient roots, out of reach and therefore ineffectual for the principal purpose at hand.

It can be said with considerable truth that the use of the plow has actually destroyed the productiveness of our soils. Fortunately, however, this result may be said to be temporary. With surprising suddenness the soil which is supposedly ruined will respond with bumper crops, providing it is supplied plentifully with organic matter properly incorporated into the surface. This generous response by soil thought to be "worn out" shows that our farmland has not been exhausted by cropping but has been rendered impotent by inept management.

Our faults are oftentimes excused on grounds of necessity. Plowing, however, can summon no such defense: there is simply no need for plowing in the first instance. And most of the operations that customarily follow the plowing are entirely unnecessary, if the land has not been plowed. It is possible to farm land without a smoothing harrow, without a cultipacker, without a drag, without a roller, without a single implement which is ordinarily used after plowing--in preparing the seed bed. The single exception to this is the disk-harrow, which is used to incorporate the trash into the surface as fully as possible. If the land has been disked without previous plowing, there are no clods whatever; consequently there is no need to use the customary smoothing equipment.

"Soil conservation" is a phrase which has been widely used but little understood. There is undoubtedly an important sense in which we must save soil losses, must prevent dissolved plant food from escaping down our streams; but that is only a minor part of the task ahead. The main job is to activate and to put into biological circulation minerals that, since the beginning of time, have been locked in the crystalline structure of rock of the earth's surface. Our failure to solve that problem generations ago resulted in our adding commercial fertilizer to land, not because the land holds none of the minerals contained in the fertilizer, but because we had not found a way to dissolve those minerals so that crops could use them. We now know how to perform this trick; so the future of soil conservation work is destined to be concerned more with releasing additional minerals from the soil rock than with saving losses which by comparison are relatively light.

Fortunately, however, the same practices which result in prying more minerals out of the rock result also in maximum saving of the previously dissolved minerals. Whether we call the method "conservation" or "proper soil management" is immaterial; but it is important that we consciously imitate the natural soil profile which always and everywhere leaves *all* the organic matter on or mixed into the surface.

Since plowing cannot leave organic matter on or in the surface except under such conditions as the pioneers found when they first cleared the land (when the entire soil mass often was black with intermixed organic and inorganic materials to a depth of a foot or more), plowing, as it is now done, is definitely out as a means of breaking the land surface.

When plowing is stopped, erosion will stop with it, for the organic matter mixed into the soil surface will cause that surface to appropriate the rain as it falls, thus removing the flow of water which is essential to the processes of erosion. Therefore, the cure for erosion is automatic when soil is again created, for soil does not erode.

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TRADITIONS OF THE PLOW

THE ANSWER TO THE QUESTION, *Why do farmers plow?* should not be difficult to arrive at. Plowing is almost universal. Farmers like to plow. If they did not get pleasure from seeing the soil turn turtle, knowing the while that by plowing they dispose of trash that would later interfere. with planting and cultivation, less plowing might be done. Yet farmers are encouraged to plow. Deep plowing is approved; or, in lieu of deep plowing, farmers are advised to cut deep into the subsoil in every furrow. Such advice comes from farm papers, bulletins, county agents, and a long list of other sources from which farmers commonly welcome suggestions and information. There should be clear-cut scientific reasons to justify a practice so unanimously approved and recommended.

If there are such reasons I have failed to find them in more than twenty-five years of search. As early as 1912, when my classmates and I were taking courses in soil management and farm machinery, we brought up the subject, quizzing professors as to why plowing, rather than a method of surface incorporation, should be the generally accepted practice in breaking the soil. A number of answers were offered, none, however, of a scientific nature; in the end some embarrassed instructors had to admit they knew no really scientific reasons for plowing. They suggested that the most important justifications for the practice might be that it "turned over a new leaf" for the farmer by the complete burial of preceding crop residues, thus leaving the land free from obstructions to future movements of planting and cultivating machinery.

Our experience was not unique. The editor of one of the leading American farm papers has this to say in a letter written to me on August 5, 1937: "It is a subject I became interested in about eighteen years ago. I made a two-thousand-mile trip among soil specialists and farmers and everywhere asked the question: Why do you plow? I was rather amazed at the unsatisfactory answers I received. Apparently farmers do not really know. When I summed up the answers it seemed that they had only one good reason for plowing, and that was to get rid of weeds." [Philip S. Rose, then editor of the *Country Gentleman.]* That there may be good reason to doubt whether the plow does even that is indicated in an article in the January, 1941, issue of this same publication, in which one writer points out that plowing may preserve for future germination more weed seeds than it destroys.

In all truth, the ultimate scientific reason for the use of the plow has yet to be advanced. My own position, however, has already been advanced in earlier pages of this book. If I were advising farmers on the subject of plowing, my categorical statement would be *Don't*-- and for that position there is really scientific warrant. A brief review of the reasons frequently given for plowing will give opportunity to point out the error involved in each.

An administrative officer in the department of agriculture of one of the New England states suggests in a letter that plowing is designed to allow oxygen to reach the roots of plants; he suggests, too, that plowed soil will not dry out so rapidly as unbroken soil. His reasons seem to cancel each other, indicating that he had not considered these two suggested effects simultaneously. Letting air into the soil is an efficient way of drying it out, particularly that portion which is disturbed. Since the roots of crops must develop first in this inverted (and necessarily dried) section of soil, it seems that my correspondent really gave a good reason for not plowing.

This idea--that it is necessary to let oxygen into the soil--has been in circulation for many years. It seems that those who pass it on do not pause to examine its implications. In a world organized as this one is, air is all pervading, except where something else fills the space. There is considerable space throughout all soils from the surface down to the level of ground water. Part of it is filled with capillary water, which clings to the rock fragments themselves; but since the spaces are too large for capillary water to fill them completely, air must fill the rest. When the water table rises, this air is forced out of the soil; when it recedes again, the air re-enters. [Water table is the name given to the level of water below the surface of the ground. The level rises and falls in response to seasons of great or little rainfall. This ground water is the source of supply for perennial streams and springs. It is literally filtered water, since it has to pass through several feet of soil before reaching this low level. Streams supplied entirely from the water table are, therefore, clear at all times. Farm wells must be dug deeper than the lowest level to which the water table ever falls, or they become dry during long continued droughts.]

It might be objected that more oxygen is required in the soil than can enter the undisturbed mass. Perhaps. In that case we should study the undisturbed forest floor. The surface of the soil where the giant sequoias grow was suitable for their needs a thousand years before the moldboard plow was invented. It is not thinkable that such giants could have developed in the absence of an optimum amount of oxygen in the soil. It must be, then, that growing plants do not require more oxygen in the soil than naturally enters it in the absence of water. There may be extreme situations, for example, where the soil has been excessively compacted by the trampling of animals or people, requiring special treatment. It is not clear, however, that plowing would be the right treatment. The freezing and thawing of soil in winter usually assists a well tramped path to grow up in vegetation the following season, unless the use of the path is continued.

Ordinarily the publications of the government and of the various state institutions can be quoted freely. The information they carry is designed for public use, and wide distribution is desirable. Ohio State University's *Agricultural Extension Bulletin No. 80* is the only exception to this rule I have seen. It was copyrighted in 1928 and reprinted in June, 1940, still retaining the copyright. The reprinting of this bulletin justifies the assumption that its contents are still considered correct. Significantly, along with other government and state publications as well as the books on soils of the last decade or two, it takes for granted that the farmer knows why he plows. The text then proceeds to describe "good" plowing as the complete burial of all trash--so complete that none is exposed even between the furrow slices. This, therefore, may be taken as the more or less official point of view.

Various books on agricultural subjects published around 1910 do give what may be considered hypothetical reasons for plowing. Most of them are vague enough to be interpreted in a number of ways. Here is a list:

a) Soil structure is made either more open or more compact.
b) Retention and movement of water are affected.
c) Aeration is altered.
d) Absorption and retention of heat are influenced.
e) The growth of organisms is either promoted or retarded.
f) The composition of the soil solution is affected.
g) The penetration of plant roots is influenced.

This list was compiled from a single paragraph of a well-known soil text which was written in 1909. Though the authors did not realize it at the time, it is a bit of literary gumshoeing around a highly dangerous subject. The intent, apparently, was not so much to give information as to indicate in what various categories the student might expect to find it. The implied assumption is that plowing improves the soil as environment for plant roots. The practice could scarcely be justified otherwise. Just how this improvement is accomplished is left wholly to the bewildered student's imagination. And while he is trying to rationalize this puzzle he is likely to conclude that, if plowing really does improve the soil as a site for plants, the vegetation growing so lush on unplowed land must be to some extent underprivileged. Of course, even an astute student may miss that angle. It is obvious that most of us did.

Assuming plowed land to be better for plant growth, we should find grass growing more freely on plowed land than on similar unplowed land near by. Weeds, too, should show preference for plowed land. Volunteer growth should take over and develop more rankly after land has been plowed than before. Is this so? Observation is that, until plowed land has subsided again to its former state of firmness, plants develop in it quite tardily, if at all. When dry weather follows the plowing, it may be weeks or even months before either natural vegetation or a planted crop will make normal growth. The fact is that "bare" land, which notably erodes worse than soil in any other condition, consists almost wholly of land that has been disturbed recently by plow or cultivating implement. The only other bare land is that which has been denuded of top soil by erosion or other forces. There is significance in the fact that erosion and runoff are worst on bare land, and that bare land is deemed above.

Take a casual glance at the landscape. Not only does the unplowed land continue to support its growth nicely while the plowed land is recovering its ability to promote growth, but even the margins of the plowed field itself continue to support their growth. Such evidence causes the argument that plowing produces a better environment for plant roots to backfire. The loosening up, pulverizing, and inversion process seems a first-rate way to make good soil incapable of performing its normal functions in plant growth. The explosive separation of the soil mass wrecks temporarily all capillary connections; the organic matter sandwiched in further extends the period of sterility of the soil because of dryness. Therefore, it is not strange that plowed soil is bare. Before it is plowed, grass, weeds, and other vegetation grow normally because there is unbroken capillary contact from particle to particle, extending from the water table to the surface. After plowing, this source of water is completely cut off until the organic matter at the plowsole has decayed. Hence the soil simply takes time out from its business of growing things until its normal water supply is restored. There is no mystery about it. It is only the working out of natural law. Wishful thinking is peculiarly ineffective in preventing this undesired outcome of plowing.

Another objectionable feature of plowing is the merciless troweling administered by the moldboard to that portion of the furrow slice which is brought from the plowsole and exposed to wind and sunshine. The effect is not noticeable, and probably not damaging, if the soil to the full depth of plowing is dry enough to crumble; but in these days, when all soils seem to become more troublesome to handle, it is seldom that spring plowing can be done early enough, if the farmer waits for the wet spots to dry out to a sufficient depth. Too often in his haste to get the year's work started, he rushes into the plowing while the soil glistens as it leaves the moldboard. Some men even plow when water follows them in the furrow. Such management of the soil certainly is playing fast and loose with resources which the soil might contribute to crop growth.

Plowing done when the furrow slice is plastic creates clods; every clod is so much soil mustered out of service for the season. The tremendous pressure necessary to separate the furrow slice from its base compresses effectively any soil that is moist enough to be plastic; and a moderate amount of clay in plastic soil serves to harden the mass upon drying so that adobe-like clods result. Smoothing implements may reduce the size of these lumps, but as clods they are likely to remain aloof from the rest of the soil throughout most of the growing season.

Such evidence of damage done by the moldboard has passed unnoticed by farmers as well as by most other people. Several reasons may be given to account for the public's blindness to obvious faults of the moldboard plow.

To begin with, conditions such as modern farmers face were remote indeed when the plow was first used with a crude moldboard attachment. That was two hundred years ago. The English countryside at that time was chiefly unbroken forest. The land that had been cleared of trees still was not very well subdued, for it was a hopeless task to try to keep the soil free from competing weeds and shrubs while a crop was growing. The forest was forever trying to recover the lost ground, and the only really effective tools farmers had against encroaching saplings, perennial weeds, and other unwanted growth were crude hoes, mattocks, and spades. Such plows as they had threw the soil both to the right and to the left. They did not cover trash very well, much less uproot permanently the wild growth which cumbered the ground. The "bull tongue" plow of the South is of somewhat the same design as most of the plows which preceded the moldboard.

Into such an environment the moldboard was introduced. It was a godsend. Pulled by an ox, or even by men, this plow would actually lift and invert the soil. This made it possible, by careful work, to eliminate completely the perennial weeds and some of the smaller shrubs. And, what was more important, the farmer who previously could manage only a few square rods now could raise food on an acre or more. Such an invention at a time when England was never far from actual starvation captured the imagination of rural people everywhere. It was electric in its effects upon contemporary thought. The population now could eat regularly and well, provided enough farmers could have moldboard plows.

Inventions did not occur often in the early eighteenth century. New aids to living were rare indeed. The moldboard plow, destined to revolutionize the living conditions of world populations, marked the beginning of a new era. So completely did it fill the greatest material need of a poorly nourished mankind that it was accorded a place in people's thoughts such as is usually reserved only for saints and priests. The plow had saved humanity almost literally.

The farmer of that day, in both England and America, had more trouble keeping unwanted things from growing than in getting his crops to grow. For him, then, the use of the plow was excellent strategy, because temporarily, at least, conditions were created which made it impossible for the weeds to grow. This gave the farmer time to get his root and grain crops started before the wild vegetation recovered from the setback caused by the plowing. Once his crops were well started, the incomparable richness of the black, loamy soil kept them well ahead of the weeds. Now that the black loamy soil has completely disappeared from most land in the United States, our proper strategy may well be the exact opposite of what was advantageous then. His plowing, even though it covered a lot of organic matter, could not create for him the sandwich, organic matter profile (OMP), for there was too much depth of blackness in the soil.

The earliest crude moldboards could not be favorably compared with the burnished products of today's factories. Hammered out by hand at forges erected at or near the ore mines, they could become smooth only through much use. They were designed by guess after many trials and did not become stabilized to dependable shape until a century after farmers began to use them generally. Despite its shortcomings--much easier to appraise from our perspective than from that of the contemporary farmer--the plow was, even in its crude state, the greatest invention of the age. It dispelled hunger as the first oil lamp dispelled darkness. Aladdin's lamp could not have been more wonderful.

When a century later the first experiment station was established at Rothamsted, England, no one seems to have raised a question whether the neat work done by the moldboard plow might be responsible for the trouble farmers were beginning to have growing crops. The men of science who manned that first station, as well as those in charge of the state experiment stations later established in this coun try, inherited an unquestioning reverence for the plow. The doctrine of the Divine Right of Plows passed down from generation to generation, so that the possibility that the plow might account for the waning fertility of the soil never seriously occurred to anybody along the line. For decades, to my own personal knowledge, men have sensed that the plowing in of a layer of organic matter at the plowsole must of necessity interfere with capillary movement; but the subconscious feeling that The Plow Can Do No Wrong apparently prevented anybody from doing anything about it. The result is that, although we have had experiment stations in this country for more than three-quarters of a century, no one of them conducted tests, before 1937, designed to compare directly the effects of plowing, on the one hand, with the surface incorporation of all organic matter on the other. Failure to do this has definitely handicapped the development of basic soil information which might easily have prevented the debacle toward which American soils have been drifting.

The failure to harmonize the implications of ordinary observations with really scientific information may be the result of historical lag, or an attitude of mind, or mere carelessness, or, finally, a combination of all three. If we consider the published recognition given to the importance of organic material in the soil surface, especially since the opening of the present century, it is difficult to avoid assessing blame, on the score of carelessness, against those who did not look beyond their immediate data to the estate" fished data gained from plowing. This is almost implicit in the following:

The *Yearbook* of the United States Department of Agriculture for 1903 carries this statement on page 284: "Decayed organic matter, by itself or in combination with mineral soil, absorbs moisture much more rapidly than soil containing little or no organic matter; hence, the greater the amount of leaf mold and other litter, the more rapidly will the rain be absorbed. Rapidity of absorption is also influenced by the degree of looseness of the mineral soil. In the forest the mulch of leaves and litter keeps the mineral soil loose and in the best condition for rapid absorption."

If such a statement seems sufficiently old for its validity to be questioned, compare it with the following, taken from pages 609-10 of the *Yearbook* of the same department for the year 1938: "Forest litter--the carpet of dead leaves, twigs, limbs, and logs on the forest floor serves in several ways. Water falling as rain on bare soil dislodges silt and clay particles by its impact. These are taken into suspension and carried into the tiny pores and channels between the soil particles as the water makes its way downward. Very shortly the filtering action of the soil causes the openings to be clogged by the particles; water can no longer move downward through the soil, so it flows over the surface carrying with it the dislodged silt and clay; and erosion is actively under way. A protective layer of litter prevents this chain of events by absorbing the impact of the falling drops of water. After the litter becomes soaked, excess water trickles gently into the soil surface, no soil particles are dislodged, the water remains clear, pores and channels remain open, and surface flow is eliminated except in periods of protracted heavy rains."

I can detect no significant difference in the meaning of the two quotations. The latter gives a more intimate picture of the processes involved, but it fully confirms the less graphic description in the earlier statement. Moreover, every intelligently conducted experiment so far undertaken in this direction confirms the truth presented.

A paragraph from a letter dated February, 1940, should be interesting in this connection: "The

Department of Agriculture has long been interested in developing new methods of soil treatment which will maintain and build up the organic matter content of the soil. Studies carried out by the Soil Conservation Service at a number of locations have already produced unusually outstanding results along this line. At Statesville, North Carolina, for example, it has been found that several inches of pine needles spread over the soil surface reduced the loss of soil by erosion to a point almost beyond measurement. There was also a considerable increase in the organic matter content of the soil and indications point to a worthwhile increase in crop yields. In Nebraska subsurface tillage, which leaves straw and other litter undisturbed on the soil surface, has proved remarkably effective in reducing soil and water losses and in preliminary experiments has led to a material increase in the yield of several crops tested." This was signed by the Assistant to the Secretary. It may be said that my letter, to which this was the reply, had mentioned and asked for comment on the fact that the moldboard plow had never been put to test for validation. No mention of the matter was made in the official reply.

The fact that no advance whatever is apparent, when the statement of 1903 is compared with those of 1938 and 1940, indicates that effort to implement the earlier findings into general farm practice has been neglected. The statements from the yearbooks refer to forest soils, of course; but that fact must not obscure the larger fact that the findings discussed concern principles of universal application. Principles which are valid in the forest are valid in the field, always; so it seems that researches into the importance of organic matter on the surface of crop land should have been started as soon as the earlier announcement had been made. If any such work was begun earlier than 1937, I have been unable to find any record of it.

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"RESEARCH"
Unsponsored . . . Unconventional

IN STRICT HONESTY, the heading of this chapter must be enclosed in quotation marks, for I am not a research worker in the conventional sense of that phrase. The work that originated the theories of this book is called research only for lack of a better name. It did, however, give the necessary direction to my thinking, and that is a chief function of any research.

It all began as an attempt to grow vegetables in soil which, as I discovered too late, was better suited to brickmaking. Thousands of people have made equally futile attempts, but they have had sense enough to quit when their corn stalks refused to exceed the diameter of a lead pencil or the height of a man's knee. I couldn't quit, for to quit would have left us with two thousand square feet of our back yard without grass and full of weeds, with no easy means of getting it back into lawn again.

It had been our custom always to have a vegetable garden. When we bought our home, it soon became apparent that the grass in the back yard was largely yellow dock. That fact gave excuse for digging up this section of the lawn, growing vegetables in it for a few years while we got rid of the weeds, and then either continuing the vegetable garden or putting the area back to grass. What actually happened was something far different.

A man was hired to do the necessary spading, while I went about my commercial business. When I returned later and paid him off, I discovered that what had been exposed in the spading was nothing but the toughest of white clay. The clods when dry were as sharp and firm to the touch as so much broken stone. I had had experience with several widely different kinds of soil, but this was an extreme condition which I had never before seen. Eventually the story came out, but not before we had tried for a year or two to grow something edible from that pure clay.

Our house, it appeared, had been the last one constructed on our street. The site had been low--some three or four feet lower in places than the general level to which the surrounding lots had been graded. The owner had invited the contractors to dump on this lot. So, above the original soil that had been there lay three to four feet of plain clay of the heavy character that prevails in this former lake bed. It was just "cellar dirt," with no discernible sand, silt, or organic matter to relieve its harshness. It was so hard when dry that I could put my full weight on a sharp spade without making any perceptible impression on it. Ordinary highway traffic could have traversed it without leaving a track; though when wet it would cling to my shoes in gobs as big as I could carry.

Mellowness in such a soil is unknown. It is either too wet or too dry for stirring, with only half an hour or so between the two conditions when it may be cultivated with impunity. Ordinary soils never get into such a condition, because usually there are some fragments of organic matter in them, and these greatly alleviate what would otherwise develop into a tight structure. This mass of clay had been excavated from levels far beneath the usual depth to which roots penetrate, so it had no supply of organic matter. In the language of experiment station men, it was "an organic matter check plot." Its use for growing crops would show what might be expected of land in which there was no organic matter.

In the beginning I was not concerned about soil theories, but wished only to produce vegetables for home use. However, it soon became evident that I must concern myself somewhat with fundamentals of soil management or I wouldn't get anything for my work. About this time I recalled that a quarter of a century earlier, as county agent of Whitley County, Kentucky, I had tried unsuccessfully to show farmers how to improve their very poor, sandy soils by plowing down tall rye. All the early county agents probably tried this; and all of them learned, as I did, that it would not work. At that time I had decided that, if the opportunity presented itself, I would try to solve the problem.

The problem really was simple--apparently. Its essence was to find a way to put large quantities of organic matter into a very unproductive soil without ruining temporarily its ability to grow crops. It seemed that so simple a problem might be solved easily. The opportunity I was looking for (in an experiment station) never came. Instead, after having been out of professional agriculture for several years, I now had the identical problem dumped rudely into my lap--without the appropriate surroundings usually considered essential.

Such was the beginning of what proved later to be the solution of that original tantalizing problem. I tackled it without definite plan, not realizing fully for several years that I was at work on the problem first presented to me in Kentucky. It is clear, therefore, that to call this research without proper explanation and qualification would be to debase the high meaning of real research work. Such work is always preceded by carefully organized plans and pursued by accepted methods.

The elements of accident and coincidence are important in this project It was purely accidental that of the half a dozen properties we had inspected before buying, we should have selected this one. In fact, only the night before we concluded its purchase, we had decided to buy another on the next street; but, upon notifying the owner, we found that it had been sold the previous evening to friends of ours who had suddenly made up their minds to buy. It was coincident that ours should have been the newest house on a street where none was very old. It was the merest coincidence that the site had been depressed.

More than this, the combination of circumstances in my own earlier life had favored and prepared me for just this thing. The farm on which I grew up was bottom land, almost entirely surrounded by hills. The hills were then in process of being cleared for agriculture after having been lumbered off. I had seen the same fields pass through several alternate periods of cultivation and neglect, and had noted that the mere growth of weeds and briars had renewed productivity on such land. The bottom land we owned was farthest from the stream, the highest of the entire bottom-land area; consequently the flood water that covered it once a year did not remain long, and, therefore, did not settle out very much debris to improve the soil. This fact had resulted in the abandonment of this higher ground in favor of land nearer the stream; and, since our portion had been considered worn out by the standards of 1883, my father paid little for it. This land had declined in productivity to such an extent that its production would not exceed twenty-five bushels of corn per acre, a yield considered no longer worth the effort when there was near-by land that would grow one hundred bushels without manure, fertilizers, or any other amendment.

We owned, therefore, the poorest land in the bottoms; and my father was pitied by the neighbors when he bought it. I have since seen one-hundred-bushel crops of corn on this same land, and from its productiveness three of my brothers and sisters and I were educated through college, and two others were educated as far as they wanted to go. For many years the strip of land we owned stood out as the greenest part of all the bottoms, even though, as time passed, it no longer had the benefit of the decomposable material which the river water at one time brought. The neighbors meantime viewed with critical eyes the strange things my father was doing on that land. He hauled in manure from a near-by town, also ashes from a tannery when he could get them, and he bought a carload of fertilizers each spring, part of which he resold to any neighbors who were willing to take a chance on such stuff. And, while he was doing this, the neighbors continued to depend upon the decreasing increment of flood debris from upriver.

The sons of those neighbors now manage the land. They decided that my father's methods were worth trying. And now, after several years of the younger generation's management, that old contrast has almost disappeared, for all the bottom land has come under better management. And, incidentally, it may be said that farmers the country over now are being paid to do for their land what my father did for his throughout his lifetime. He read farm papers regularly. He tried the methods that seemed reasonable to him. He adopted what proved to be profitable. And he had the luck to be engaged in a business which, in that location, paid the highest return for liberal treatment of the land. He received good prices for staple truck crops marketed in the near-by town in the heart of what was then a coal mining area. General farming, of course, would not have repaid the costs of such treatment, either then or now; but that does not invalidate the fact that my father, starting with poor land, had made it productive. He did so at high cost. I believed it could be done at lower cost. And, the important point--by far the most important point--was my absolute confidence that the poorest of land anywhere could be made highly productive, since the undisturbed natural landscape is always highly productive in virtue of its continued year-after-year production.

With this background of home training, my general knowledge of scientific agriculture, and a decade of experience in professional agriculture in two states, it seemed to be a strange chance that I should buy the particular spot where the stage already had been set to force me into solving the old organic-matter problem.

Starting with the original spading in 1930, some organic matter was put in each season. In general, the quantity was increased as time went on. Eventually, a system of introducing leaves was developed which was very like plowing, but in quite exaggerated form. A trench was made to the full depth of the spade blade. This trench was filled with leaves, sometimes dry and bulky, sometimes wet, compact, and heavy. These were tramped in. Then the soil from the adjacent strip was thrown onto these leaves as the next trench was spaded. Repetition of this process resulted in creating virtually an organic matter subsoil beneath the surface soil. By 1937 I decided that the organic matter profile (OMP) thus created was in effect simply a magnification of the sandwich OMP produced by plowing; also that the layer of organic matter that varied in thickness from nothing to as much as four inches became an irresistible magnet for any water in the soil, as truly as if that organic matter had been blotting paper. Once that decision was reached, it became obvious that the way to determine whether such was the situation would be to remove the leaf layer at the next spading and not establish such a layer gain. So, in the fall of 1937, the area was spaded without putting in additional leaves. Care was taken to remove the entire mass of leaves from spade depth, mixing these in with the upper layers of soil.

In 1938 the soil surface was as different as possible from its condition in any previous year. Each spring before 1938 it had been necessary, in order to enable small seeds germinate in the stiff clay, to cover them with fine sand instead of the clay. By such tactics I had been able to grow parsnips in this heavy soil. In 1938 it was so plainly evident that nothing of the kind would be necessary that parsnip seeds, carrots, lettuce, and all the small seeds were planted without any covering other than the granulated clay that was everywhere. The whole soil surface in 1938 was as granular as sugar, and it could be raked about just as easily as if it had been sand. So changed was this condition that I planted garden peas on March 11, a week earlier an the local gardeners on sandy land were able to plant them. Every crop planted in 1938 thrived, whereas, prior 1938 no crop could be depended upon except under special conditions.

One especially fine bit of evidence was the behavior of head lettuce on this soil in 1938. A gardener friend of mine, with whom I was discussing the fine condition of the soil, challenged the possibility of growing head lettuce on it. He was so sure of it that he agreed to furnish the plants. Since the area was small I took only six plants. These were set into the soil, and once they had started nothing whatever was done for them except to keep the weeds down. No fertilizer was used, and no other treatment--not even water. Late in June this gardener came at my invitation to see how his lettuce plants were doing. They had reached almost the same size as his own, and were well headed--something he knew would not have happened in his sandy soil unless plenty of fertilizer and manure had been used. Any gardener will recognize this behavior of lettuce as unusual; indeed, most gardeners will refuse to believe it could have been true under the conditions I have described.

On July 14, 1938, by special arrangement with the Soil Conservation Service, representatives of that agency visited this project to check the soil conditions I had claimed existed. For purposes of this test, during the soil preparation in the fall a strip about six feet wide had been prepared as a check plot, as experiment station men would call it. This strip had been spaded without removing the leaves that already underlay it, and had received an additional supply, just as the entire area had been receiving for five or six years. The purpose of this strip was to illustrate the marked difference in soil texture as between the check strip and the rest of the garden.

Using a soil auger, these men followed instructions I had previously prepared, to insure that the point would be properly demonstrated. They bored into the soil in many places outside the check strip, finding that the soil was mellow to about one foot in depth, and with moisture uniformly distributed from top to bottom. There was no concentration of water at any level, and no dry, hard layer of soil anywhere. Moreover, there was no layer of leaves to be found.

In the check strip conditions were different. The initial turn of the auger flaked up the flinty hard soil from just under the surface mulch of cultivated soil. The upper eight or ten inches of soil were quite similar to this subsurface crust. It was excessively dry, whereas elsewhere in the garden there was no excessive dryness. Beneath this thick layer was the organic matter, moist, but not noticeably wet. Just under the organic matter was the moisture which should have been well distributed throughout the entire depth of soil. This check strip showed plainly one reason why crops can not grow immediately in a soil where a great deal of organic matter has recently been plowed in. There was no moisture whatever in the subsurface layer, and without moisture to dissolve plant food and carry it into the roots no growth can occur. The reason for the absence of moisture was that it had been absorbed by the underlying layer of leaves--even though the leaves did not seem moist. Their apparent innocence of moisture resulted from the fact that organic matter, as before stated, holds water within itself--just as a sponge does.

The reasoning that accounts for the flinty zone above the organic matter is so elementary that I should be embarrassed to admit that years were required for me to reach that simple conclusion. It is based upon facts so well established as to be known even to uneducated people. Yet one more illustration may help to make clearer the way this happens.

The water had been pulled downward in obedience to two forces: the blotting ability of the organic matter, and the force of gravity. Everybody knows that a bushel basket of corn cobs, if dry, could be carried by a small child, but when wet would be a load for a man. And, if they are exposed to contact with water, the wetting of cobs is automatic. To a degree, that is exactly what had happened to the water supply of the soil above the leaves. Within three or four days after the very heaviest rainfall, the excess water from the upper layers of soil would have been pulled away from the plant roots and into the underlying leaves. This produced noticeable effects. Immediately after rain, all crops were stimulated, and made rapid growth. By the end of three or four days, this stopped short, and no further growth could be observed until after the next rain.

It was with pleasure that I had set about planning the demonstration which had been inspected by Soil Conservation Service representatives. These men, not knowing the background of experience upon which I based my conclusions, could not agree with me that my check plot illustrated the normal effects of plowing--in exaggerated form. The soil dryness, recognized as common following the plowing in of great quantities of organic matter, was not caused by that plowing, they were sure. They did not agree with my conclusions. Neither did their superiors in Washington. We had correspondence following their report, as a result of which I was eventually informed that my project had "so exaggerated the effects of a bad practice" that it could scarcely be considered of value. The letter that carried this bit of unintended self-contradiction, dated November 10, 1938, was written by a man who had spent some forty years in the service of the United States Department of Agriculture and was to retire the following week. When I replied to his letter, the answer received from Washington informed me of his retirement, and gave the obvious information that he could not reply officially.

The refusal of authorities to accept and profit by the perfect demonstration I had made of the harm wrought by plowing was deeply disappointing. It had been clearly shown that the cause of the drying out of land, where considerable organic matter has been plowed in, is that organic matter. There could be no doubt of it. Stung by this flouting of an obvious point which should have been accepted gracefully, I decided that a further demonstration on field scale must be made. The story of this work appears in the following chapter. However, had I known it, this second demonstration was not needed; for, without indicating that he was interested in the matter at all, one leading agronomist of the United States Department of Agriculture had taken me seriously enough to set up a demonstration. Perhaps the intent was to disprove my theories; on the contrary, the outcome of the tests completely confirmed them. (I have been informed by this agronomist that he had nothing to do with initiating this test work. However, the fact remains that no surface-incorporation work of any kind had ever been done by any government agency prior to 1937 when I began nudging the department to do so.)

The results of this official experiment proved that, by working organic matter into the surface instead of plowing it in, the resulting grain yield could be as much as 50 per cent greater. The very first year of this trial showed such a result. So unexpected was this outcome that a report of it was published in the November, 1939, issue of *Country Gentleman*, under the title, "Right Side Up Farming." [George S. Pound, "Right Side Up Farming," *Country Gentleman*, Vol. CIX, No. 11 (November, 1939), 78.] Such publication was a radical departure from traditional practice. Usually a result must have been confirmed by several years of follow-up work before the public is permitted to know of it, especially in a popular magazine. This unusual advance publication of first-year results seems to indicate a conviction among officials regarding the significance of what had happened that first year.

No special acumen was required for this "research." The only "facts" uncovered were so old they had been previously overlooked as of no possible application. The direction of the pull of gravity, and the affinity of blotting paper for liquids, could scarcely be pointed out as research discoveries; and those were the only discoveries involved. Their effects were amplified by the large quantities of organic matter employed, which accounted for their discov~ ery. Thus, the combined effects of downward capillarity and gravity are seen to be much more powerful forces than the wishful thinking, which previously has been depended upon to keep the soil moist above a heavy green manure crop that has been plowed in.

To have demonstrated the fact that such fundamental forces could be involved--which had remained undetected through a century of active scientific effort to improve soils --may be of consequence.

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PROOF ON A FIELD SCALE

THE RESEARCH that revealed the absurdity of our system of tillage was done as a hobby, at scarcely any expense other than time and the failure of the effort to produce the vegetables our family needed. The later work of demonstrating the workability of the idea on a field scale could not be done so simply or with little expense. There must be implements and power. They cost money. Time must be devoted to the project; whether it should be part time or full time had to be decided. If full time was to be given to this project, it had to be planned on a self-supporting basis. To justify full time, the area must be larger than could be found at reasonable rent near town. For such an area I had to go into the country beyond the reach of suburban cost influences.

Months were consumed in the development of a general plan. Some time was spent trying to find suitable property near the city that I could buy or trade for, develop, and later move to. None was found that could be bought on terms that would leave funds for operation. Failing in that, I decided to lease land and operate it while still living in town. The land selected was eight miles distant, but was otherwise very well suited for the work I expected to do. It was sandy loam soil, which would be more workable than the clay had been in the early stages. The owner's husband reserved for his own use the entire front of the farm along the highway. This provided a screen against too great curiosity concerning the strange methods about to be used. The portion of this land that was most promising for cropping had been used all along by a neighbor farmer-gardener to grow corn and hay. Other areas had on occasion been put to garden crops. A good deal of the area had been virtually abandoned because the owner and her husband could not manage it themselves, and none of the neighbors would rent it.

After leasing the land on February 20, 1939, I waited in vain for weather suitable for seeding rye or oats, later to be disked in as green manure. Rain fell almost incessantly. Until April 15 there was not more than half a day in any week when the land was dry enough to work. Oats bought for seeding had to be sold again. For green manure, I had to depend upon weeds the land would grow before it had to be prepared for a crop. This quirk of weather was to prove a serious handicap before the season was over. It prevented the creation of the single condition upon which success with crops is assured--an abundant supply of organic matter which may be worked into the land. (I did not realize then as I do now that it would have been possible simply to throw the seed on the land, even when it was too wet to work, and grow a green manure crop without stirring the land at all.)

Failure to establish green manure crops contributed heavily toward the financial failure of that first season's work. Had I sensed this in advance, much fruitless effort would have been saved; but, though the work was not rewarded financially, the gains in knowledge fully compensated for the monetary loss. Lessons learned through those experiences in the field made it possible thereafter to take advantage of weather rather than to be always its victim. For farmers such knowledge will be of inestimable value.

During those first rainy weeks I designed and built a crude device for locating the rows and establishing the places where seeds or plant roots were to be placed in those rows. I knew that in some circumstances green manure crops might grow so tall before the land could be worked that they could not then be completely incorporated. In such a case none of the customary planting or transplanting equipment could be used; for all machines for purposes of this kind are designed to operate by sliding through a fairly smooth soil surface. Any considerable amount of trash on the surface would make such implements useless. It was imperative, therefore, that I be prepared in advance to deal with trash on the surface, if green manure crops were so heavy they could not be put into the ground completely. The outcome of that necessity was a marker which would roll over the land, smooth or otherwise, and, without furrows, indicate the rows and the hill spaces in them. Rolling rather than sliding motion was the obvious answer. The marker was made from two discarded wagon wheels. These were fitted on their rims with lugs that would "track" the land at one foot intervals; the axle upon which they turned was designed for row widths of three, three and a half, four, and five feet. With this implement I felt confident that any surface, however trashy, could be planted.

I was to find later that its ability to negotiate a trashy surface was no the most notable virtue of this marker. Even more important was the fact that, every time a marker lug touched the ground, it compressed with some 150 pounds of weight a vertical column of soil directly beneath the bottom of the track it made. This compression served to reconnect the soil particles which had necessarily been separated by the stirring of the surface. Pressing these particles together again restored what we may call the "wicking action" of the soil, enabling capillary water to rise without interruption to the bottom of the marker track. Anyone who has used an oil lamp will perceive the significance of this.

Compression was the principle upon which the marker worked. Where the idea originated, I do not know. Perhaps it was the result of an illustration we used to see in one of our soil texts. The illustration was intended to show the student how a well prepared seedbed should look. The light color of the surface soil indicated that this loose, "well prepared" surface soil had been dried out by wind and sunshine--as is always true even though the area presented was supposedly ideal for seed growth. Included in the picture was a heel print. The moist condition of this compressed spot, darker in color, proved that capillary water climbed the vertical column of soil immediately under it. The comparatively dry condition of the rest of the soil surface showed that, in the loose soil, the capillary connection with the deep underground water supply had been broken. Thirty years ago, the picture meant nothing more than a clean-cut photo of an exceptionally well prepared soil in good tilth (according to established standards). Fitted into the new scheme of soil management, it becomes a significant guide to better methods of planting seeds and transplanting plants.

It is impossible now to trace the effects of the old picture on my thinking about soil conditions during a thirty-year period. But that scarcely matters. The important thing is that after thirty years the idea actually incubated. At this writing, the incubation of the idea is about as far as the process has gone. No one, either among practical farmers or among professional agriculturists, seems willing to accept an idea so different from conventional methods of planting and transplanting.

Every crop we planted in 1939 and 1940 was established by use of this compression marker. More than eighty-five thousand plants were involved, without any artificial watering whatever. Seventy-five thousand of the plants were shipped from southern Georgia in hot weather, yet no water was used in transplanting them. In some cases this may have been unwise, but this was not the chief cause of the considerable loss of plants in 1939. In 1940 there were no losses worth mentioning.

Our method involved encasing the plant roots in soil which already was being supplied with capillary water from below. Roots laid in the marker track and covered with firmed earth were considered properly set. They stood erect by next morning, always. Exceptions to this rule were sweet potatoes set in soil where the quantity of organic matter disked into the soil had been greatest. In 1939 only one field had enough organic matter, and this was the accumulation of several years of dead weed stalks. The field was on a high ridge, and was of sand so light that summer crops had died out for lack of water. The only plants that could survive the hot summers were uncultivated ones like weeds. It was impossible, therefore, for the owner to rent this land to the neighboring gardeners or to manage it successfully himself. That is how it happened to have grown up in weeds for several years. When I leased it, this field became the first area on which I tried to develop workable methods of disking organic matter into the soil. The weed debris was so heavy in places that it could not all be worked in, and some spots tracked by the marker failed to become moist with capillary water afterward, because a layer of underlying weed fragments would absorb the water and keep it from rising to the surface.

Such details had to be learned. Before we learned them in 1939, we lost a good percentage of the sweet potato plants that were set in this field, because the particular site they occupied was underlaid by absorbent organic matter that kept their roots from getting water. From this experience we learned to scan the marker tracks in transplanting; if the bottoms were not moist, even on a hot day, we searched for the underlying organic matter that prevented moisture from rising to the surface. A year later, after four-foot rye had been put into the surface of this field, sweet potatoes planted exactly the same way were ninety per cent perfect stand. This is good for sweet potatoes in any situation. Success depended upon the actual presence of capillary moisture in the marker track.

One highly amusing incident occurred in this connection. While the tomato field was being transplanted in 1939, one of the neighbors, having observed that something unusual was being done in our field, came over to inspect the technique we were following in transplanting. When he saw that we were using such "careless" methods, he shook his head sadly and cautioned us that plants handled so recklessly could not grow satisfactorily. His displeasure was evident when he left the field a little while later. He considered us a stiff-necked lot, unwilling to learn from a farmer of more experience. Later in the season, when we were picking the crop, he got as much pleasure from complimenting us on our superior stand of plants as we did from noting his changed point of view. He even enjoyed laughing at himself; but the whole situation was still mysterious to him.

The conventional method of transplanting large areas such as commercial gardens, tobacco fields, and so on, usually involves heavy machinery, made heavier by the load of water it must carry to provide a little for each plant. Our method, involving only two people, a hoe, and a basketful of plants, seems ridiculously inadequate by comparison. The results of this simple method, though, were far better both in 1939 and in 1940 than the customary method achieved locally. With the exception of sweet potatoes, we had better stands of plants than our neighbors had in 1939; and in 1940, because of the extremely wet condition of the land, we could go ahead while our neighbors had to wait for the land to dry out enough for their horses or tractors and transplanting machines to operate. (Incidentally, about five weeks elapsed before the land was dry enough.) The dry weather of 1939 and the excessively wet weather of 1940 seemed not to affect our results. The catch of tomato plants was virtually perfect each season.

It may seem that an unwarranted amount of space has been used in this discussion of the preparation of the land for transplanting and in describing the methods used. Justification for such extended elaboration of this matter is found in its illustrative value; for, if any doubt remains in the reader's mind as to the folly of plowing, comparison of the water relationships that follow plowing and disking ought quickly to dispel any such misgivings.

If rye three feet tall had been plowed in on this land, no capillary water would have been available to plant roots next day, or even next week. Scientists agree on the drying effect of great quantities of organic matter plowed in, though their reasoning on the subject is somewhat different from mine. The behavior of these plants, set in compacted, disked soil, should forever dispose of any faith in plowing. It proves perfectly the superiority of disking when great quantities of organic matter are involved.

If the purpose of breaking the land is the removal of trash so it will not interfere, then the moldboard plow is the only implement to use in starting preparation of the land for crops. It happens, however, that the crying need is for a soil surface similar to that which we find in nature--with all of the organic matter near enough to the surface that plant roots can appropriate the products of its decay. This being the object, the way to attain it is to use an implement that is incapable of burying the trash it encounters; in other words, any implement except the plow.

If space permitted, much could be said about the behavior of crops on land prepared in the unorthodox fashion that has been described. The first season's crops did not produce a satisfactory yield, because little organic matter was available to supply the needed nutriment materials. Sweet potatoes on the disked weed field were the lone exception, and, had their stand been good, they would have returned a profit that season.

The selection of sweet potatoes as a commercial crop for this latitude (only ten miles from Lake Erie) will puzzle many readers. I had observed that they grew successfully in home gardens; that they had earlier been a commercial crop locally; and that yields locally averaged much higher than the average for the United States. A successful exotic crop would enable me to succeed in a market dominated by some of the country's most capable gardeners. No novice could compete with these skilled men in the production of cauliflower, cabbage, sweet corn, or lettuce; but I hoped that, with a high yielding, non-competing crop, I might survive and make some money.

My confidence in the sweet potato arose from the fact that I had produced on very thin soil, many years earlier, a small amount of this crop, the yield of which had figured about twelve hundred bushels per acre. The fact that this amazing yield was produced by soil treatment practically identical with the new methods I intended using encouraged me to hope that I could duplicate that small-scale result on a field basis. While I failed to do this, careful appraisal of the behavior of the crop justified some important constructive conclusions.

For one thing, the sweet potato crop theoretically requires 120 days of frost-free weather to mature. Weather records show that in Ohio, where I was planting, about four months intervene between the last spring frost and the first frost of the autumn. However, in 1939 these plants produced a mature crop in just sixty days, proving that the time element is not as important as the ready availability of the wanted plant foods. Owing to the poor stand of plants, as well as to the slow start most of them got, the yield for the field was but little above the average for the country; but the speedy showing of those which did get a fair start made it impossible to overlook the implication that better mixing in of organic matter with the soil would have resulted in a tremendous crop. This one and a half acre field alone could easily have paid the entire expense of machinery and operating costs of the whole farm and produced a profit besides.

Of equal importance was the discovery that sweet potatoes produced in this relatively dry climate may not require artificial curing as do the roots produced in the much more humid climate of the Southeastern states. My crop of 1939 could have been stored successfully just as the roots came out of the ground. It is by no means certain that the crops of other seasons would be as free from moisture as those of 1939; indeed, it is known that sweet potatoes produced in my area of Ohio do rot easily, however, it may be true that sweet potatoes produced largely from organic decay are less moist than those produced in a highly mineral soil. This possibility deserves investigation.

My faith in the sweet potato as the potential mortgage lifter was high, and I had acted accordingly, by transplanting five acres of the farm to this crop. None of the land except this first field had any considerable amount of organic matter--only the self-grown weeds. The catch of plants from the other fields was excellent, but because the substance was not in the land, these fields did not produce marketable roots. In 1940 the only sweet potatoes set out were put on the field that had done best in 1939. The catch of plants was very good, at least 90 per cent; but during the entire growing season there was not enough heat and moisture (at the same time) to permit the plants to produce a satisfactory crop.

Considering all of the evidence, it seems that, for all but the occasional, exceptionally cool seasons, the sweet potato is a dependable crop for this section, provided the land is well filled with organic matter at the surface, and provided the transplanting is properly done. It should be remembered that all of these plants were from southern Georgia, and were transplanted without watering after having been two or three days on the road in hot weather. Even with these handicaps, the catch, wherever capillary water was available when the plants were set out, was exceptional. I expect, therefore, to continue to try to produce sweet potatoes on a limited scale. Whether the product could be stored without artificial drying is really unimportant in this section, for the Cleveland market would at any time absorb the production of a few hundred local acres. The first-grade potatoes I grew in 1939 brought a premium price throughout the season.

When the outcome of the 1939 season had been analyzed, it seemed fair to assume that, had the supply of organic matter been sufficient in all fields, the sweet potato crop alone would have made it a profitable season. With this view of the matter, I was not discouraged, even though considerable money had been lost in 1939. I could not foresee, of course, that the 1940 season would be so extremely wet in the months when crops usually are getting started that the plants could not even be put in. This was true throughout this entire section. None of the gardeners succeeded in planting any considerable part of their usual acreage of vegetables. Some prepared the land repeatedly, even to distribution of the fertilizers, then did not have an opportunity to plant. I was lucky enough to get tomatoes into the ground on the only day between May 25 and July 4 that the work could have been done. Many fields were set to tomatoes in mid-July with plants that were ready for setting in mid-May. It was a very unusual season in every way. Therefore, since I received income from only about two acres in 1940, quite naturally I did not make any money. The season's effort just about paid for itself.

Like 1939, 1940 taught me some important lessons, even though it disappointed me financially. There was ample organic matter, in the form of tall rye, on every field. Seasonal conditions made it impossible to get the rye disked in at a suitable time for planting the planned crops. With the exception of a few minor crops, the entire farm income was from tomatoes, beans, and cucumbers. Each of these crops was handicapped by weather conditions, but the results in each instance were encouraging and profitable.

The tomato crop around Cleveland in 1940 was disappointing. Many growers said it was the poorest season of their experience. Extremes of wet followed by drought, and again by wet weather, produced many cracked fruits. Though there were many such in my crop, there never was a time when it was impossible to get marketable tomatoes. Most growers had to abandon their early plantings even before their later acreage began to bear. I had but a single acre in cultivation. It increased in vigor as the season advanced, and the product was in good demand at premium prices all the time. Sometimes I got as much as 25 cents a peck above the top price in the Cleveland market. One reason for this was the exceptional weight of my packed pecks. Fifteen pounds is the standard weight of a peck of tomatoes. In 1940 my crop averaged more than that. It was not unusual for a peck to weigh sixteen pounds, and many weighed seventeen. Most local tomatoes in 1940 weighed from ten to fourteen pounds to the peck. The exceptional weight of mine, and the quality it indicates, justified the premium prices I received.

The bean crop was extraordinary, too, for several reasons. At the outset, six feet of rye had to be disked down before the field could be planted to beans. And when I say down, the expression is accurate. In many places so thick a layer of rye covered the surface that the disks did not actually touch the ground. There was no help for it. If beans were to be planted in this land, they had to be planted in spite of this condition, and so they were. The marker was run over the field, spacing rows three feet apart. Wherever the marker had "walked" over the straw without even parting it, the straw was parted by hand and the beans were planted on the solid ground, covered with a hoeful of earth from near by, and left to their fate.

The stand of beans was so perfect that it was commented upon by trained agricultural men who saw the plot during the succeeding weeks. This indicated to me, at least, that a finely worked seedbed may not be essential to success. Compare this method of planting with the one described by Ben Ames Williams, as I have quoted him on page 31 from *Come Spring.*

Since it was impossible, with the marker I had, to plant rows closer together than three feet, it seemed a waste of good space to plant this area to beans only; therefore alternate rows were planted to cucumbers. This spaced the cucumbers properly; moreover, it gave me an additional crop to grow and observe. Limitations imposed by distance made it difficult for me to get the bean crop to market, as well as to get labor out from town to pick it, so it was well that no more beans than I harvested had to be handled.

Cucumbers proved more significant as objects of observation than as a source of income. Yet, considering that this was ordinary farm land, converted to experimental garden use by the disking in of a single crop of rye, it is not surprising that beans produced better than cucumbers. Beans are better suited to hard soil conditions than are cucumbers. Indeed, cucumbers are quite insistent upon an abundance of readily available plant food--preferably decay products. In this raw soil, only partly prepared for a good cucumber crop, the quality of the fruit that actually matured was extremely high. Every cucumber was as dark green as if it had been grown under perfect growing conditions. Several grocers who took quantities said they expected to sell them as hothouse grown. There would have been no fraud, for the quality was there. From the excellent quality of this fruit, it may be determined that any land that had been prepared by a succession of disked-in crops should produce cucumbers of unsurpassed quality and in great quantity.

Beans, however, were more remarkable in their response to this supposedly crude environment. Aside from the perfect germination already described, they continued mass blooming as long as there was available water in the soil to permit it. The plants held buds for blossoms, blossoms, immature beans, and beans ready for picking all at the same time through a long period several weeks. Naturally, the yield had to be harvested over a correspondingly long period. Five pickings--all full but the last--were required. And, even after we had quit harvesting beans for market, enough late-set beans matured to provide plenty of seed for a good-sized bean field again.

Such persistence of cropping is unusual in beans. Most bean plantings are abandoned after one picking, or at most two. One local gardener who was equipped for irrigation told me that he had used nitrogen in order to stimulate bean cropping. He seemed proud to announce that he had had to pick his plants twice after using nitrogen and irrigation. My crop was produced without either, and under conditions that assuredly would have made irrigation profitable at certain stages. Considering the severity of the prevailing weather conditions, the fact that these beans produced two hundred bushels of marketable beans per acre seems to me quite important. It seems to indicate that, if the land were so thoroughly filled with organic matter at the surface that it would again begin to look black, it should then grow bean plants that would commence yielding in spring and not cease until frost in the fall.

In all of this, no mention has been made of the fact that in 1940 no nitrogen fertilizer was used anywhere on the farm. That fact is one of outstanding importance in summing up the significance of the project. It will be obvious to any experienced reader that such crops as I have described could not have been produced without a plentiful supply of nitrogen. It will be equally clear that land of ordinary quality could not have supplied the necessary nitrogen for good quality garden products. Only black land--black with decaying organic matter--is ever expected to produce good crops without the addition of some nitrogen in the form of fertilizers. Indeed, without applied nitrogen, such land usually produces no marketable crop at all; and the plants exhibit a yellowish, rather than a healthy, dark green, color. Usually, too, no crop at all results from such nitrogen-starved plants.

As far as I was concerned, these plants were nitrogen-starved for I had intentionally omitted the use of nitrogen. The reasons, for its omission would be difficult to state, but in my home experience we often had too much, rather than too little, nitrogen, and for that reason we often suffered serious crop setbacks. Because of these unfavorable experiences with nitrogen, I have never believed very strongly in its application.

Full explanation of how my recent crops managed to get a sufficient nitrogen supply is given in a later chapter, the strangest, perhaps, of the whole book. It partakes of the mystery of Aladdin, along with the romance of smuggling, but it is a very true story withal. Reserved for another chapter, too, is the story of how these crops defeated insects and diseases. The success of the crops was in no way owing to the use of insecticides, fungicides, or other means of battling pests, for none of these aids was used.

The net result of these two years of field work was the conviction on my part that the human animal assumes in error that he can really improve on nature's well-designed arrangements for nourishing plants. Faced with the necessity of thwarting competitive growth in order to promote the plants he favors, man has rashly overstepped the bounds of biological propriety by performing operations on the soil which waste the very plant foods his own plants require. The troubles he has, then, are the consequences of this original error. My tests have proved that, to avoid trouble, man needs only to return to methods imitative of nature's own. Quite a cheerful discovery, that.

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SOIL BY MACHINE

WITH A GOOD DEAL OF TRUTH it may be said that we have allowed our soils to degenerate chiefly because there have been too generous supplies of good soil everywhere over the face of the earth. The existence of these fertile areas, and particularly the discovery by Columbus, at an opportune time, of a few hundred million extra acres previously unheard of and unsuspected, served to make man's way easier. As long as this condition obtained, it was not imperative that man learn how to provide tillable soils where none existed.

It is now time, however, that the truth be realized. *We can recreate soil wherever good soil formerly existed, and we can do so by machinery.* Any exceptions to this categorical statement will be found to result from human mistakes, as, for example, land made untenable by the silting of the streams that naturally would drain it, or desert sands robbed of both their water-holding clay and the conveniently shallow water table. For the whole category of areas that have suffered merely water erosion, however severe, there is still the definite assurance that as good soil as ever existed upon them can be restored.

Much the same can be said of areas damaged by wind erosion, or, by excessive cropping and grazing.

Nature did not put precisely the same kind of soil everywhere. There has been a great variety of difference in soils because of the complex forces by which they were created. That we need not go into here, except to say that the one thing all soils had in common was organic matter in or on the surface. We need not be interested in the slightest as to whether the soil was what the scientist calls a podzol, a prairie, a chernozem, or just plain dirt; the significant thing about each of these, in the virgin state, was the quantity of organic matter it contained, which implies also the conditions under which the moisture supply would permit the maintenance of a certain amount of organic matter in the soil.

It is not even necessary that soil be of brunette shade in order to produce well, although soils made productive by nature always reveal their quality through the presence in them of decaying organic matter, which is necessarily dark in color. (The single exception to this statement--if indeed it can be called an exception--is the desert area to which irrigation water has to be supplied. Such soil is rich by reason of the suitable minerals which are brought up from the soil depths by water, which, on evaporation, leaves the minerals in abundance. The dependence of desert soil on irrigation really rules it out of this discussion.) Enough organic matter can be put into the surface at a single disking to make any ordinary soil productive almost immediately; yet the quantity of organic matter introduced at one time may be too little for its decay to influence the color of the soil. This was true of the soil I farmed in 1940, with rye three to six feet tall disked in to serve as the organic source of nutrients for my crops. I could never detect any of the dark tint which is associated with organic decay, yet the crops behaved as if there was plenty of fertility in the soil.

The blackness of virgin soil is the result of a cumulative process more or less complex, since it involves repeated deposits annually of plant, and possibly animal, debris upon the soil surface--to which must be added the destructive effect of an innumerable biologic population which lived and died in this environment and contributed in turn toward its enrichment. The effects of the resulting black deposit in and just under the surface--not in an impassable layer several inches under the surface--kept all the water absorbed by the soil in the same zone that plant roots would be searching for it. The supposition that for hundreds of years nothing had disturbed its surface does not satisfactorily account for the fertility of the soil. We have developed some useless theories in that field. Men have come to feel, for example, that centuries are necessary for the development of a productive soil. The satisfying truth is that a man with a team or a tractor and a good disk harrow can mix into the soil, in a matter of hours, sufficient organic material to accomplish results equal to what is accomplished by nature in decades.

In nature, long periods were occupied in developing the black OMP of the meadow or forest because the mixing in of organic matter was a task mainly for bugs and worms. The soil surface was their home environment. They worked slowly but painstakingly, and they developed that first essential of all life, the health of the land.

This has been true, necessarily, of the natural formation of soils everywhere. The grasses of the plains developed thicker, blacker layers of organic matter in the surface because they were annual plants. They died down each fall. New growth came up each spring. The dead plants accumulated, and were mulled over by the living things of the soil surface. Only a few years of this process were necessary to develop the tough sod the settlers found when first they undertook the gigantic task of plowing it. It is not surprising that in many instances ten-ox teams were necessary for the purpose.

The forest did not lay down organic layers as deep or as black. Why? Because the decay of leaves each year was more complete, and the material was re-used in tree growth. The farmer who cleared the land got merely the "crumbs" from the forest's "table." It could not be otherwise.

With the halo of mystery thus stripped from the mechanics of natural soil building, it no longer appears impossible for men to create their own soils as needed, and where needed. It has to be remembered, too, that when the soil of an old forest site has been restored to a condition as productive as the one which originally existed, there will not be the necessity of waiting for stumps and roots to rot out, as was once the case, before the land can be handled profitably. Many a farmer of another generation found that, by the time these interferences were out of the way, the soil was no longer productive. The modern farmer has a big advantage in that he can simply disk in a crop of green manure whenever he chooses and withdraw a good portion of the decay products in the first year's production. And the process lends itself to infinite repetition.

Historically, we are told, soils are very different in their origins. So different, in fact, that their adaptation to specific crops is affected. The more correct view is that these idiosyncracies of soils were developed only after the original organic profile had been destroyed and most of the organic matter used up. On good virgin land, the chief production limitations are due to climatic factors rather than to the peculiarities of soil origins. My experience in growing sweet potatoes is a case in point: the plants had completed their growth in two months, rather than four, on land near Lake Erie quite outside their normal habitat. The presence of sufficient organic matter in the soil, a plentiful supply of water in the organic matter, and the prevalence of hot, sunny weather all combined to overcome any adverse factors. I had been told by a Virginian, a local buyer for a chain-store organization, that sweet potatoes could not be grown successfully in this locality. I was disinclined to believe him. When the crop matured, he bought part of it, paying about 25 cents a bushel above the prevailing market price for the best southern-grown roots.

Personally, I doubt whether one type of soil is any better suited than another to a given crop, provided each soil is supplied with an abundance of organic matter in the surface. Note the fact that a *liberal* quantity of organic matter is stipulated, and that it must be *in the surface*. If two soils so treated are subjected to similar climatic conditions, however different they may be in origin, their respective crops will be too little different to indicate a substantial superiority for either. In other words, sweet potatoes--definitely preferring sandy soils will produce heavily on tight clays, provided first the clays have been richly endowed with a supply of organic matter in the surface. I have already produced parsnips in heavy clay so treated; the yield figured 1,220 bushels to the acre. Parsnips ordinarily are grown in sandy loam.

I am not prepared to say that the mere disking of organic matter into the soil surface is the complete remedy for all adverse soil conditions. There are too many unusual conditions of which I have too little knowledge. My acquaintance with soils is not broad enough to justify a complete generalization for all soils. However, unless we are prepared to question the universal application of theories and principles that have been proved by generations of use in other fields, we must admit the widespread applicability of this idea of surface mixed organic matter as a remedy for many, if not all, of our soil troubles. Also, the fact that all applicable experiment station results support the idea gives additional weight to the contention I have advanced.

We do not have any implement that is well suited to the incorporation of organic matter into soil surfaces under all conditions. The disk harrow is a good one to use under a great variety of conditions, but even it has its limitations. It can not be used in soil that is very stony, even though it would successfully follow the plow in such case. It is difficult to manage on side hills. Unless special techniques in its management are used, the disk harrow does not leave a smooth surface. Some of these difficulties could be overcome by the use of power lifting devices, but such devices are of no use to farmers who have only horses. Yet, until somebody invents a better implement, the disk harrow is the one tool that can be substituted for the plow in the successful preparation of land (not in sod) for cropping. Its use for this purpose, however, is so different from its traditional role of smoothing up after the plow that a few hints should help the farmer who wants to try it. Such a routine as the following will work best:

1) Be sure the disks are sharp and free from rust. Have the entire implement in good working order, all grease cups or other oiling arrangements fully supplied with lubricant. This last is especially important, for the disk harrow was not designed for heavy work like land breaking. Work of this kind will subject it to very unusual strains, so it should be kept perfectly lubricated all of the time.

2) Use only the front section of the implement as long as you are trying to cut into the soil. Detach the rear section after reaching the field, for it will be useful in the final work of smoothing up. If it is allowed to follow along while the front section is trying for depth, its weight will tend to keep the front section from running deep enough.

3) Weight the front section heavily. Here is where some of the extra strain comes in. The plow is so designed that it naturally seeks a certain sub-surface level and therefore does not require weighting. The only force that urges the disk harrow into the ground is gravity. Weight adds to this force.

4) Set the disks to cut in--how much is difficult to say--but try adjustments at different angles to see what the effect is. Do not be surprised, though, if, on the first trip over a field, you can not see that the disks have cut in consistently. Usually they will have cut in slightly, even though the dirt is not thrown up sufficiently to be seen.

5) One important procedure to observe in putting in a tall, strawy crop, like rye, is to lay it all down in one direction, then cut across it at an angle. This serves to cut the straw into lengths that can be worked into the soil easily. For this work, of course, the disks need to be sharp. Also, there are limits to the amount of rye that can be managed by the disk harrow, however sharp the disks may be. Experience is the best guide here; no rules can be laid down.

6) It may be that a clay soil in a very dry condition will not yield at all to the disks. In that case, it probably will help to run over the field once anyway. This will ride down the green manure crop so that it will lie closer to the surface. Some improvement in moisture content of the surface soil should result. Later, say in a week, a second attempt to cut into the surface is likely to be successful. Failing this, wait for rain.

7) Farmers who have always used double disk-harrows may need to be told that when the front section alone is used it should always be lapped half way each time in order to leave the land smooth. This is very important if the disks are cutting in, less so, of course, when they are not.

8) Following the routine outlined below will make it possible for the operator to do a smooth job, or at least a smoother job would result than if this method were not followed. You may be able to work out a better plan for your own situation. This is offered as a suggestion, assuming a square or rectangular field:

Decide first which way you wish to make all turns. With some outfits, left turns can be made better; with others, the turn is easier to the right. Since all turns are to be the same, it is necessary to determine this in advance.

Start along one side of the field and follow the boundary to the limits of the field. Turn along the border and follow it about four or five *widths* of the harrow; then torn and follow a line parallel to the first direction to the opposite limits; return to the beginning.

Repeat by lapping the harrow a half width *toward the middle of the field* as you follow the earlier track. At the ends no lapping is possible, since in going one direction the previous cut of the implement is to your right, or in going the opposite direction it is to your left. At the ends you must make this change of sides.

In the above three paragraphs you have the simple directions for what may be called a "spiral" disking routine. If you begin by crossing one end of the field, then your progress is very gradually toward the opposite end, by these crosswise trips that inch over one half the width of£ the implement each time.

Also, after about ten times around the "spiral," you begin to catch up with the forward side of the original first-round track. At this point you may wonder what to do. The answer is to continue just as you began, lapping one half width all the time, until you reach the opposite end of the field with the forward track. Then you will have double disked the first ten rounds and the last ten rounds, while all ;between will have been quadruple disked. In other words, most of the surface will have been stirred four times with the disks, but the end strips will have been stirred only twice.

It could be that, by the time you have gone over the entire field once in this fashion, it will be in proper condition for the final smoothing However, I have usually found that, in order to prepare land sufficiently well to make the use of cultivating equipment possible, it is necessary to repeat this process exactly as indicated, except that the disk is run crosswise the direction taken by the original work. Of course, if the routine just described was preceded by the operator's going once over the area and riding down the green manure crop, the quadruple disking operation will have reduced this material to six-inch lengths. In that case, it is likely that once or twice over with the reassembled harrow may serve to complete the seedbed sufficiently to make planting possible. Do not expect it to look as smooth as it would if the land had been plowed, even after you have done all the smoothing possible. And there may be at best some trash visible here and there. Neither the lack of perfect smoothness nor an occasional bit of trash will be fatal to the use of ordinary equipment; though in planting it probably will be necessary to delay the work occasionally long enough to remove from planter shoes accumulations of the trash. A little patience in this respect will be richly rewarded later, for you will find that the crop will be much less subject to drought damage, will require absolutely no nitrogen fertilizer, and will yield out of all proportion to customary standards. This will apply, regardless of the kind of crop grown.

You may or may not have to smooth the final work of the disk with a drag. Certainly you will not have clods to contend with. Compacting is likely to be important if the weather is dry. However, the disk harrow may be used for this purpose, not as effectively as a regular roller or corrugated compacting implement, but with the disks set straight and heavily weighted it does a fair job.

One caution should be given concerning cultivation. I came near ruining one corn crop because I failed to discover that there was enough uncut straw in the surface to lift slightly almost every hill of corn as the cultivator passed. The rye on this field had been six feet tall. It had proved impossible to work it in at all, and much of it lay there, not even cut into sections. If you should have that same condition to contend with, delay the first cultivation until the straw has had time to disintegrate sufficiently that it can not interfere. This will not require long, providing a little rain falls. If the weather is dry following the planting of the corn, two or three weeks may be required. Success in this respect is wholly a matter of careful observation and management.

Of course, if you encounter such conditions as have just been described, you can not hope to plant the area by means of ordinary equipment. It was to make planting possible in such a surface that I devised the pressure marker. Planting after this rig was used had to be done by hand, but the manner in which the crops grew fully justified the hand method. It can readily be seen that, if the planter can expect several times the customary yield per acre from soil so recreated, he is justified in conceding something to painstaking care. Again, if it is possible, by renewing the soil with green manures, to cut the usual acreage to one-fifth, one-third or one-half, the concession is scarcely a concession at all.

Eventually, it is to be hoped, suitable implements will be devised and put on the market. Meanwhile, I anticipate modifying to some extent the plans I followed in 1939 and 1940. Instead of growing green manure in quantities sufficient to make incorporation impossible with the disk harrow, I hope to spend more than one season in getting the land ready for crops; then, after working a two-to three-foot rye crop in early in spring, some summer crop will be seeded to be put in later--to be followed by rye again. This would involve two green manure crops each year. Not many such short crops would be required, it would seem, to make the soil begin to look black again. And, treasonable as it may seem, I hope that while this routine is in progress each crop will be accompanied by the germination of multitudes of weed seeds. Disking in immature weed plants with each green manure crop may be an excellent way to reduce weed growth. More is said about this in a later chapter.

It might easily be that some land would be so refractory to disking that the first crop of green manure could not be worked in at all. This event need not stop your efforts. Do not plow it in. Or, if you do plow it in, plow the land again immediately, and a little deeper. If you do plow twice, you will have created a superior soil situation by that means, for the second plowing will have returned to the root zone your mass of green manure. In this position the disk harrow will be able to reach and cut it. To your delight you will discover that no clods form in connection with the work, so the follow-up operations usually necessary can be cut quite short.

Double plowing it not a new device. Friends of mine recall that the farmers of a previous generation often plowed down clover in the fall, then plowed the land again in spring for potato growing. Apparently the method worked well. However, much decay of the clover must have occurred during the winter, and the leaching away of much of the products would have been inevitable. Moreover, the decay of this material made it possible for the farmer to do a much neater job of plowing in spring than might have been possible had the land been plowed twice in quick succession. Many a farmer who decides to plow down a heavy green manure crop and follow up immediately with a second and slightly deeper plowing will be thoroughly disgusted with the idea before he has gone many furrows. The appearance of the resulting surface will be disheartening to farmers who have always taken pride in the neatness of their plowing.

The trouble here is not the appearance of the surface but our notion of what constitutes beauty. Few people realize how thoroughly we have become enslaved by the idea that nothing effective can be done toward preparing land to grow crops until the land has first been plowed. Plowing has been accepted as axiomatic--a necessary prelude to every other operation. Even though the work of the plow has been for many years associated with the deterioration of our land, we still have not awakened to the fact that, to solve the problem, we must cease plowing; or, if we wish to continue to use the plow, we must do the work in a different way. The methods we use, whatever they be, must produce a surface that is filled with debris that will rot. Let the surface of the soil wear a "beard" of exposed material, if need be. That condition will eventually become beauty in the soil. "Pretty is as pretty does" is not a new saying. It is particularly applicable here, for trash-filled soil alone is capable of the highest quality yields. The ancestry of a soil is a very minor matter in comparison with the present ability of that soil to supply to hungry roots a soil solution enriched by abundance of decay products.

An alternative to double plowing land that can not be managed by disking is to leave the area wholly undisturbed. This may seem an acknowledgment of failure, but the matter should not be prejudged. Much will happen to an intractable soil while the crop it has produced is decaying. The decay of a green manure crop, in place, will of itself serve to start a heavy soil surface on its way toward granulation. When granulation has proceeded sufficiently, a clay soil can be worked like sand. Moreover, if the crop in question produces seeds which any annual crop will do--it will reseed itself naturally; and, without any work what ever, the farmer will have a second, volunteer crop of green manure to reckon with. This second crop will be very easily managed when the time comes to disk it in.

It has to be admitted frankly that the preceding paragraph is a deduction from the known effects of the practices described. For this reason, the conclusion may be considered vulnerable. My best suggestion is that anyone who is inclined to doubt the feasibility of the plan advanced should try it on an area of supposedly unmanageable clay. I have seen clay become so friable, under conditions that were comparable to those suggested here, that it could be raked about like sugar. The same clay, before treatment, was so solid that a sharp spade, with a man's weight upon it, was scarcely enough to make an impression upon the surface. I am certain, therefore, that further experimentation will sustain my contentions.

The abandonment of the first season's work in order to let nature cure the ills of the sod may seem a waste of time. The economy of such a procedure must await confirmation until the outcome of subsequent crops can be observed. The eventual result will contain its own proof. And my guess is that those who know soils best will be the last to doubt the eventual outcome, for the renovating effect of decaying organic matter, which induces granulation of the soil, is well known and accepted. The only new thing about it is the method proposed for securing that effect.

Doubtless, the creation of soil where none now exists, through incorporation into the surface of materials grown upon the particular area, presents many difficulties not touched upon in this chapter. The idea is entirely too new to have been thoroughly investigated in all of its ramifications by a single unsponsored student in a single season of work. It is extremely doubtful, though, that the actual re-creation of soils presents any technical difficulties which can not be surmounted. The only requirement for the establishment of a new tillage system, apparently, is investigation along one or both of two lines: first, the adaptation of our customary use of existing surface-stirring implements to the job of incorporating liberal quantities of green manure; or, second, the invention of new equipment capable of disposing of all organic matter by surface mixing. No further time should be lost from the accomplishment of one or both of these objectives.

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KING WEATHER DEPOSED

ALL PRACTICING FARMERS and students of agriculture are well aware of the controlling influence of weather in the growing of crops. To the city man a sunny day in midsummer may be a thrilling event, because it provides the ideal conditions for picnicking, hiking, and swimming. For thousands of farmers near by the same day may be an occasion of disaster involving the local food supply, in which the city dweller, as well as the husbandman, has a vital stake. Rains that arrive a day too late to save potatoes, beans, and lettuce affect both producer and consumer, but the producer more seriously.

Weather has always been considered in the category of "acts of God," and so it may very well be. Equally, how. ever, it may be said that "God helps those who help themselves." There is nothing to be achieved here by bringing up once again the famous dispute between the Forest Service and the Weather Bureau as to whether forests actually increase the rainfall. Nor is it to the point, perhaps, to conjecture with the scientists concerning the effect of England's deforestation in the seventeenth and eighteenth centuries on present-day climate in the British Isles. But it may be useful to point out that man has it in his power to disturb some of the moisture conditions essential to plant growth, and that, by extension, he partly controls some of those conditions.

Man can conserve the moisture laid down by the heavens, or he can waste it. The earth he took over originally was covered everywhere by a water-soaked, sometimes odorous sponge of humus. Nature maintained this water-catching cover through successive plant generations, wherever man did not disturb, and continues to maintain it down to this very hour. By imitating nature, man could have enjoyed such benefits as he has never dared hope for; by disregarding the obvious example she set for him, he has courted disaster.

Irregular moisture has been regarded as the most important weather condition controlling crop growing. With respect to moisture, the absorbent mat we find everywhere in nature serves a purpose which has not been recognized in agricultural literature. For lack of a better term, we may call this its "reservoir" purpose.

Farmers leave their hay stacked in the field exposed to all the rain that falls. They know that none of the rainfall can sink deeper than the upper few inches, because the porous tissues of the hay must first be filled. Since every inch of this top layer of hay will catch and hold nearly an inch of rainfall the underlying hay is protected.

Knowing this, we should understand that if enough organic matter is disked into the soil surface it will constitute to its full capacity a reservoir in which a large proportion of the rainfall will be retained. If enough absorbent material has been provided to hold an inch or two of rainfall, then, when rain is falling, an inch or two of it will be retained in the surface. Naturally, this spongy mass will supply water--richly endowed with the minerals it takes from the decaying material in which it is held--to crops which otherwise would suffer seriously in the intervals between rains.

Not having this conception of the service of such a mantle of porous material, scientists have reasoned about water chiefly in terms of capillary movement within the soil. And, strangely enough, some scientists have believed, from results of their tests, that there is little such movement in the upper layers of soil. If anybody doubts that such conclusions have been introduced into serious scientific literature, it may be interesting to relate a brief conversation I had in September, 1937, with a crop specialist I had known for nearly twenty years. It ran about like this: I had suggested doubt as to the propriety of plowing. He quickly asked, "What's wrong with plowing?" "Interferes with capillarity," I replied. He had a ready answer: "Tests show that there isn't as much capillary movement in the soil as we used to believe existed--it's relatively unimportant in many cases." "Well," I replied, "in unplowed land there must be enough upward capillary movement between rains to keep the vegetation alive." Mine was the last word.

He was correct in his statements. Such tests have been made. They were made, like all soil experiments, on plowed soil. The "reservoir" for water lies several inches deep in the plowed soil; and, since it literally robs the upper soil layers of their water as well as shutting off upward movement of capillary water rising from deeper in the soil, no other results of such tests could have been expected. If such tests were made in soil where grass is growing, the story would be entirely different.

The very nakedness of plowed land should of itself indicate a lack of capillary water in the surface. If capillary water were present, seeds would sprout and grow, for seeds are always present. Or had you noticed that the only bare soil in most landscapes is that which has recently been plowed? I discovered that highly significant fact only a few months ago, though I had seen it daily throughout a lifetime. Since plowed land is always bare, and since practically all other land, save areas like the Sahara, is covered with greenery of some sort--which could not exist without a continual supply of water--it follows, even without tests, that there is no capillary water in the upper layers of freshly plowed soil.

It may be repeated here that, while God, not man, controls the weather, it is nevertheless given to man to control some of the fruits of weather, and of these perhaps the most important is the natural moisture of the soil surface. The first essential in this respect is to grasp the dissimilarity of water relations in plowed and unplowed lands. The next is to understand that the weather which kills vegetation on cultivated land may also cause vegetation to thrive, or at least to show no ill effects, on uncultivated land. The final phase is to connect logically the importance of the organic matter profile with both plant growth and the weather conditions under which plants may prosper.

For purposes of this discussion we may assume as normal any soil surface that has been left unplowed, or any plowed soil that has had time to recover its normal capillary water movement (because of the disappearance by decay of the organic matter plowed in). All meadow and pasture land on farms, then, as well as the land occupied by the farm fences, may be considered as part of the natural landscape, even though it is also part of the land normally subject to plowing. It is natural landscape because in its profile there is nothing to prevent water from rising to the surface. Whatever interference may have been introduced in previous times by plowing has been disposed of by decay.

By and large, the "voltage" of any soil depends upon the accumulations of decayable material available in its surface. By this standard it would be true almost always that wilderness soils, unplowed for many years if ever plowed at all, would be more productive than similar soil that had been included regularly in rotation cropping. The unplowed soil has the advantage that economical use of all decay products has been the rule for the entire period since its last plowing. The grassland in rotation, on the other hand, has periodically had a large percentage of its accumulated material removed from the surface, resulting in the wasting of the decay products. This deliberate (though unwitting) periodic waste of soil resources, after being repeated several times, finally results in a low-grade soil where formerly the productivity was high. The final result is erosion. And, when erosion has started, we may be sure there is not much absorbent material left in the surface of the soil. The remaining light-colored stuff is almost identical with that which the glaciers shunted about in their time.

An experienced farmer allows some of his land to lie in grass for a few years in order that its "voltage" may be stepped up. The longer the area is in sod the more productive it is when it is again put to corn. However, the period in which it accumulates a new supply of organic matter to be wasted again by plowing is not sufficient to enable it to make the gains that would put it in its natural condition. Indeed, the progress seems always to be slightly on the down side. No trick yet discovered has made it possible to achieve positive gains regularly on land operated in continuous three-or four-year rotation. There are probably a few exceptional cases, but this is the general rule. The wastage caused by plowing usually more than balances the accumulations made in the interim. In fine, rotation of the type described is not a cure-all for impoverished soil, and, what is more important to the thesis of this chapter, it does not get at the water relations which are ultimately desirable.

It was shown in the last chapter that a farmer may quite abruptly step up the productiveness of his soil by simply short circuiting the wasteful practice of plowing. By mixing into the surface the decayable material which the plow would inter, the farmer sets the stage for biologically economical practices hitherto unknown to modern farming. Aside from questions of plant nutrition, there are several ways in which the surface mixing of organic matter brings to focus friendly forces of growth which are unable to operate when land is plowed.

Every ton of organic matter mixed into the surface of the soil will be able to contain much more absorbed water than it could if buried at plow depth Why? Because, being weighted down by so much less overlying soil, its volume will be greater. And organic matter, it must be remembered, retains water volumetrically, while the minerals of the soil must hold it only upon the outer surfaces of the particles. Water runs *into* organic fragments, while it squeezes in *between* particles of sand, silt, and clay. We can rightly expect, then, that any absorbent material we work into the surface of the soil will retain rain water much more effectively than would the same material if plowed in.

Indeed, if plowed in, organic matter gets no opportunity to catch and hold rainfall until that water has first forced its way several inches down between the mineral crystals. Under most conditions it is much easier for of the water to run off the surface than for all of it to force its way down into the soil. This means, then, that when all the organic matter is in the surface of the soil, it is able to take in water from both above and below--and in greater volume because of the greater volume of the organic matter itself.

Undoubtedly the original black soils our forefathers knew could absorb directly, and as rapidly as it fell, several inches of rainfall in a few hours. It is unlikely that very much water ever leached through the zone of surface organic matter in those highly absorbent soils. The light, fluffy leaf mold, or the springy layer of grass roots, gradually became filled with rain water as it fell. In this connection I like to remember the story told by one of the best-known agronomists in this country. He was inspecting some highly organic soil lying near the top of a mountain slope when a heavy shower developed. The slope was a little less than 45 degrees. Those familiar with geometry will recognize this as rather steep land. This agronomist remained through the storm to observe the course of the water as it fell. He said that, so far as he could determine, none ran off. If any did so, he said, it certainly did not take any soil with it.

Disking heavy green manure crops into the surface of the soil, then, is an excellent way to create, precisely in the surface of the soil, a reserve of water upon which crop roots can draw continuously until it is used up. Such an arrangement is obviously superior to the principle of permitting the water to run down through the soil and hoping it will be brought back by capillarity. Aside from holding a plentiful reserve of water in the root zone, the mass of organic matter receives capillary water continually from below, which replaces, at least in part, the reserve from which plants are drawing. This reserve supply of water serves to tide crops over extended periods of drought which otherwise would damage them seriously. From such a source water can be made available during many more days of the growing season than could possibly be the case when surface conditions are such as to let some of the rainfall run off and be wasted. Here is "conservation of natural resources."

This, however, is only part of the story. The water stored in surface organic matter is constantly being used to assist in the decomposition of the material which holds it. It not only assists in this decay, but it dissolves and in turn holds the products released. Thus, as long as water is retained in the organic tissues, it is constantly being enriched by the cast-off substances of which the organic matter was composed. And all of this enrichment is in addition to the minerals which the capillary water has picked up and dissolved in the soil depths before the water has been absorbed by the organic matter. It can readily be seen that under these conditions many influences are working together effectively which could not do so if the organic matter were located six to eight inches deep, where relatively few plant roots reach.

At this point the reader should recall that, in the plowed soil, carbon dioxide is released into the upper layer of soil; and that this gas is prevented from becoming carbonic acid because of the necessary dryness of the upper layers. In the newer situation, with all of the organic matter just in the surface, there is provided an abundance of water in the vicinity in which the carbon dioxide can be dissolved. And, since carbonic acid is one of the most efficient of known natural solvents of minerals, its work in the surrounding crystalline rock particles serves to release for plant use quantities of phosphorus, potash, and other needed plant nutrients which would not otherwise be available.

The extent to which this release of minerals from the rock itself can take the place of applications of mineral fertilizers is something I am not prepared to discuss. It is an interesting and a very important question. Every farmer will want to know, and is entitled to know, the answer. If it is possible that the carbonic acid released in the soil will supply enough fresh minerals to supplement adequately the minerals drawn from organic sources, then the purchase of mineral fertilizers would be unnecessary. Only this much can be said safely: If a farmer succeeds in working into his soil enough organic matter to equal the supply held when the land first was opened for cropping, then he might reasonably hope to grow maximum crops without fertilizers. An easy way to test this principle is to leave unfertilized strips in all such fields. When it becomes impossible to find those unfertilized strips at harvest time, because the crop is equally good everywhere, then the necessity for fertilizers has vanished. Within a few years, no doubt, we shall have official information on this point.

And how may we expect the plant itself to react to the optimum conditions described? Just as any other being reacts to a constant supply of food. Plants will establish most of their millions of roots in the organic fragments. There is not the slightest chance here for plant food to be lost. The instant it is released, the water that contains it is moved into a plant root and sent upward into the plant. The matter of deep rooting of plants, which has been widely discussed in past years, becomes a dead issue. There ceases to be any need for roots to penetrate soil depths. Their food supply is in the surface. The water in this organic matter is busily engaged in wrecking the dead tissues in order to provide materials to be built into the new growth. Bacteria, too, are involved, and without them this process could not occur. The point is that "all things work together for good"' in this instance; so close knit is the process that no opportunity is left anywhere for the loss of nutrient materials. Plant roots that go deep, other than for anchorage, in such a situation are working to the disadvantage of the plant they represent.

It will now be apparent that man can control to a very considerable extent the rainfall with which his land is endowed from season to season. The reasons sustaining this conclusion may be summarized as follows:

Under proper management, the soil may be caused to hold natural precipitation at just the level where plant roots normally seek the essential nutrients. The presence of an organic mass in the surface so enriches the water by solu tion that, volume for volume, the water thus treated will produce more plant growth than water held in the minerals alone. Water thus held in the organic mass becomes available to plants without the opportunity for essential plant nutrients to be wasted in any way.

Considering these important factors, it is not too much to suppose that ten inches of rainfall might accomplish as much as is ordinarily expected of twenty. Again, with ample rainfall, it may easily be possible to produce several times the average production figure for the country as a whole.

The truth about the weather is that man can indeed make the best of it--if he will.

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TILE TREACHERY

"THE DRAINAGE of imperfectly drained and saturated soils used in crop production is a well established practice." True. In fact, tile drainage probably is too well established in many places. We have installed so much tile that the' community water supply has been adversely affected, to say nothing of the even more serious problem of crop yields. The wisdom that grows from experience tells us that drain tile installed where it is not imperatively needed is the surest route to low crop production.

Perhaps the most serious indictments that can be drawn against tile drainage are these: first, that the land where the rain falls is likely to need the water after it has been carried away through the tile; and, second, that innocent people downstream are apt to be disturbed by floods that are needlessly high because of water wasted through unnecessary tile installations. Tile, then, is a disturbing factor in relation to both local water resources and frequently recurring floods. It consequently becomes the obligation of everybody concerned with the elimination of an aggravating wet spot to think far beyond that immediate need before deciding to throw additional water into the streams.

That much unnecessary tile is laid with full approval of farm specialists is indicated by this further quotation taken from page 723 of the United States Department of Agriculture *Yearbook*, l 938:

> For years some farmers have seen wet spots in good fields "drown out" with loss of labor, fertilizer, and seed. not to mention the seldom considered rental value of the land. Yet they made little or no attempt at drainage until they changed from horses to tractors. When the heavy machinery mired down they decided to drain. Realizing the seriousness of the situation in holding up the sale of farm machinery, and possibly wishing to improve the farmers' ability to buy new equipment, one manufacturer published a bulletin on drainage *(Drain the Wet Land,* by R. A. Hayne, Chicago, 1921), even though the company produced no drainage tools.

These quotations indicate the authentic point of view among professional agriculturists and prove that unwise tile installations may actually be put in with full approval of farm advisers. Indeed, a careful reading of the entire chapter from which these quotations are taken fails to reveal any cautions against overdoing what is considered an excellent practice. The impression one gets is that the future success of farming rests to a large extent on the completeness with which the land area is drained. The writers certainly are not nervous from dread that too much tile is being laid in on farms.

"Wet spots" present the visual evidence that tile is apparently needed. They appear on land which originally did not permit water to stand. And as the years pass, more and more of the land that formerly needed no sub-surface drainage develops these wet spots. Before we can properly diagnose this mania for excessive drainage, we should know what these wet spots really are and why they develop where they do. It will help our analysis to consider the apparently complete lack of understanding of soil facts displayed some time ago at a meeting of potato growers when this matter came up for discussion. The incident is illuminating.

A drainage problem had been found on the land of one of these farmers. He had discovered that water stood in a certain low spot in one field. He knew that there was tile not far from where this water stood. Search after the water was gone disclosed that the tile was directly under the center of the pool. Examination at the outlet while the water still stood on the land showed that the tile was running, and that it was not loaded but that it could easily have removed the standing water. Yet the water stood for days just over this active tile line.

The land in question was heavy, lake-laid clay a few miles from Lake Erie. The verdict of the farmers in conference was that this heavy clay had been worked too much, or when it was too wet, and had become puddled. Clay in such condition conducts water only by very slow cappillarity; so this verdict was probably correct. At any rate, it squares well with the slow rate at which the standing water disappeared. Troweling by the moldboard plow when soil is too wet does for it just what a sow does to the bottom of her wallow when she finds a little water standing in it. She smears the mud with a sort of sliding roll which effectively smoothes and seals the surface against the passage of water. The next time it rains she will have a nice place to wallow, and the water will remain until it evaporates.

No self-respecting sow would try to make a wallow unless the site were mineral in character--entirely free from straw, corn cobs, or other organic debris. These latter materials would drain away the water, because the open, cellular structure of organic matter is conducive to moisture flow.

These farmers evidently had good hog wallow material, which was precisely what they did not want. They had it not only at the foot of the slope, but all over the surrounding watershed. Obviously, what they needed to do was the converse of the sow's problem, they must provide organic drainage for the surrounding slope so the water would not converge on the low ground. Their faith in tile, and possibly their firm, hard-headed American belief that the more a thing costs the more it is worth, kept them from thinking of this simple and inexpensive solution of their problem.

Water that falls on the upper reaches of a slope cannot possibly find its way to the lower ground if the intervening soil is absorbent. Really absorbent soil simply cannot conduct water over its surface. There are two forces operating to prevent its doing so, and the action of either is usually sufficient. The vertical pull of gravity is fully capable of pulling water into the soil, provided the surface has not been made impervious. And gravity is reinforced by the capillary pull of any absorbent surface. Let us suppose that a roof is covered with a half inch pad of blotting paper. How soon might we expect to see water dripping off the roof? Certainly not until the blotting paper itself was completely saturated. The identical thought applies to any slope over which water is accustomed to run. If the water succeeds in reaching the lower ground, it does so only because the condition of the surface forces it to run off.

In this connection it is very interesting to recall the remarks of a prominent agriculturist with whom I was discussing this problem. I suggested that little water could get away from a "cove" soil, and he agreed. He reinforced the thought with the information that he had seen cove soil on 90 per cent slopes and had been unable--though he watched during a heavy rain--to observe any runoff. [A cove soil is one which results from conditions that cause leaves to drift to the same spot season after season. The lee slopes of mountain tops all along the Appalachian Mountains develop cove soils, provided the windward slopes are covered with forest to produce the leaves. The annual increment of leaves keeps the soil always open, so that no water can leave the place where it falls until the entire soil mass has filled with water. The fertility of these soils is unbelievably high.]

If water will refuse to run off over a 90 per cent slope covered with a layer of absorbent material, surely we have a clue that may help solve the runoff problem on the slight slopes we usually farm. If we can make the surface layers of soil absorbent to a sufficient depth, we certainly will not have to worry about runoff and erosion, just as nobody worried about these problems when the land was new. They were not problems then.

To put in a system of drain tile on land that has developed an apparent need for drainage is a matter of economic consequence. Tile costs a great deal of money. Its installation, whether properly done or not, is also expensive. And, at best, the results may be no more than the removal of symptoms of trouble which should be attacked by more appropriate means. Certainly, in view of the necessary investment involved in tile installations, some previous work designed to make the surrounding soil more porous would be advisable before the decision is made to put into the land an outlay of cash and labor which might easily equal the previous value of the land itself.

Nobody really knows whether it is possible to restore to the soil its original porosity. We do know that organic matter on the surface, as in the cove soils, does prevent practically all runoff; but we have no way of knowing whether it would be possible to work enough organic matter into a soil to make it take in all of the rainfall. We know, too, that the actual cost of growing a crop of rye and disking it into the ground would be a mere trifle when compared with the cost of installing tile. It is certainly true that plowing a crop of rye into the soil does not decrease runoff, in fact, runoff is at its very worst on land that has been plowed and lies bare because of having been plowed.

Knowing all of these facts about the behavior of water on the soil surface, it seems worth while as a preliminary to the major operation of tile drainage to test the possibility of curing the wet spots by preventing the runoff water from reaching them. The only way water can be prevented from finding low ground is to cause it to run into the surface where it falls. To cause an eroded soil to do this might require that several successive crops of green manure be disked in. Even that, if necessary, would be preferable economically to spending the money for tile; for if we can make all of the water that falls on the land run into it, we will have done the perfect job of conserving the water supply.

Because there is urgent need for conserving water, any suggestion of additional tile installations should be viewed with suspicion. There are important reasons for this attitude:

1) In many parts of the country there is now a serious shortage of water during most of the year. Cities are enlarging the areas from which they draw their supply, taking in whole new watersheds. The water table in most farm communities is noticeably lower, for farm wells have had to be deepened in many instances in order to catch up with a receding water table.

2) Droughts are becoming more common and more serious. Generally speaking this is true over most of the country.

Both of these conditions should be considered before one proceeds with plans to lay in new tile lines. Each indicates that the reserve water supplies in most communities are too little instead of too large. It seems foolish to consider withdrawing additional water from places where there is already a shortage indicated both by the lowering water table and by the prevalence of droughts.

It should be remembered, too, that tile is a permanent exit for water from the soil. All water that reaches it will be led away. Tile may be put in for the sole purpose of removing in springtime a few hundred gallons of water from a low spot. It remains in place 365 days a year. It has absolutely no discretion as to what water to remove. It must remove needed water as freely as it drains away that which is surplus.

What of flood effects? No single tile installation is going to influence flood height noticeably, but the combined outflow from all the tile on a given watershed does increase the freshets that follow heavy rains. Indeed, some open-textured soils, when subjected to heavy rains in spring before they have settled firmly from winter heaving, actually offer so little filtering resistance to the passage of the water that it is still muddy when it leaves the tile. This is eloquent testimony to the speed with which the rainfall--even though it enters the soil--may reach the streams to add to the destructiveness of floods. Such prompt elimination of the water which finds the tile after spring rains surely can not be in the best interest either of the farmer on whose land it falls or of those whose farms it must inundate on its way to the sea.

Tile installation is considered so virtuous an act that the only question raised in connection with it is the farmer's ability to finance the purchase and laying expenses. This uncritical approach to the problem may be traced to the fact that early drainage projects often paid for themselves by means of the crops produced the very first season. These projects were designed to lower the actual water table in swamp land. Current proposed installations are expedient in character, being designed to correct trouble obviously caused by runoff.

When we realize that gravity is constantly tugging at the runoff water to drag it into the soil, the fact that all of the water does not run in is proof that something serious has happened to the soil surface, for originally all soils were as absorbent as cove soils. The change is explainable solely by the loss of organic matter. The actual mechanics of the situation may prove more difficult to understand, because of human visual limitations.

Ants and other creeping things that belong in the soil surface recognize the changed condition. They are vitally affected by it. The disappearance of organic matter from the soil surface forces a change of habitat upon some of them. When, originally, the crystalline minerals of the soil were separated by fragments of organic matter in process of decay, these small forms of life were able to enter the surface quite readily because of its porous character. Once under the surface, they found both food and water in the organic matter itself. Many kinds of these denizens of the soil surface are now unable to penetrate the purely mineral surface because of its lack of porosity. They once aided natural drainage. Now they frequently can not. It is not in our power to remedy the defect by artificial means, such as tile drainage.

We humans detect the presence of organic matter in the soil by the smudge caused by the presence of carbonized (partly decayed) material. Though we cannot see the separate fragments, passageways afforded by its porosity permit the tiny mites of life that exist in and on the soil surface to travel about underground just as we travel by subway. Every protruding stem is to them another subway entrance to abundance of food and water. Because of the dependence of these small life forms on decaying organic matter, the disappearance of the organic matter from our soils has caused a complete change in the fauna of the soil surface. The most casual comparison of biological conditions of the forest floor with those of the eroding land of our farms will show that one is teeming with a great variety of life while the other is almost devoid of it.

With the disappearance of the organic matter from a soil previously well supplied with it, then, we arrive at surface conditions just as truly desert in all essentials as the desert itself. Only the prevalence of a higher rainfall, reasonably well distributed throughout the year, prevents the pure mineral soils of the humid East from being as barren as are the desert soils of Arizona. Some of them are almost that barren in any case. When centipedes and lizards leave farm land, they do so in response to a process in nature which might properly be called eviction. The soil may still show a little dark color when the last of such life forms disappear from it, but their departure means that the organic matter supply has been reduced to such an extent that the soil surface is no longer a suitable habitat. The eviction of minute forms of life sets the stage for those large problems of drainage with which this chapter deals. The remedy is to restore at once the organic condition of the soil and with it the teeming life which feeds upon it. This is organic balance, and it never tolerates the development of conditions which the drain tile is supposed to ameliorate.

Obviously, if the water is unable to move from where it falls, the wet spots in the low places will disappear for lack of water to make them wet. And it is equally obvious that all engineering works now proposed as means of checking the damage done to the land by rainfall will be entirely unnecessary. Except in swamp areas, tile will be superfluous. And terraces, which are often more expensive than tile, may even be dispensed with.

Preliminary to any concerted action by governmental agencies to correct the present impervious condition of the soil surface, it would probably be a fine thing if every farmer in the country would plug the outlets of most of his tile lines. This would give opportunity for a great deal of water that now floods the valleys to sink deep into the ground so it could be withdrawn again by capillarity. Such a measure carried out by all the farmers on a given watershed should prove important, too, in increasing the supply of water in the wells of the community. Many a farmer would like to be able to devote to crop growing much of the time he must spend hauling water for his livestock. If he and all of his neighbors would simply plug all the unnecessary lines of tile they have put in, they would probably discover that they no longer need to haul water.

This, however, would be only one of a number of benefits. Among these, the increased supply of water available to crops is the most important. Thus the growth of plants could be increased, and the length of time during which crops suffer between rains could be reduced. There are other less obvious, but no less important benefits that will follow the plugging of tile lines. To avoid recurrence of wet spots, however, it would be well if the farmer would work a green manure crop into the soil surrounding these spots before he closes the tile outlet.

The sooner we make ancient history of many of our present farm practices the earlier we will realize that the Garden of Eden, almost literally, lies under our feet almost anywhere on the earth we care to step. We have not begun to tap the actual potentialities of the soil for producing crops.

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WHAT ABOUT SOIL TYPES?

WHEN COLUMBUS and the explorers who followed him first saw our land, there was nothing about the soil to distinguish those variations in appearance and behavior now designated as soil types. Even after the European trespass had been well under way for several generations, it would have been impossible to determine whether most of the virgin soils were chiefly clay, or silt, or sand. The whole face of the earth lay under, and mingled with, a mass of organic matter so manifest as to defy the best effort of man to discover the characteristic distribution of the soil's mineral constituents. Nowhere, or almost nowhere, could soils have been classified into categories more specific than the broad general groups now known as the forest, grassland, desert, and intermediate. Soil types as we now know them have become gradually discernible as the black disguise of organic matter has disappeared. As soils have become unproductive through the uncompensated removal of organic matter, it has become possible for us to classify them into an intricate system of groups and sub-groups with quite different characteristic appearance and behavior.

No attempt will be made to clarify the highly technical matter of soil classification. For such information the reader can now be directed to an extremely readable book on the subject, written by a man whose acquaintance with the subject is probably unmatched in this country. Charles E. Kellogg, Chief of the Soil Survey, United States Department of Agriculture, published late in 1941 his *The Soils That Support Us*. In my opinion there is no easier source from which the layman can obtain correct information on the subject at hand. After reading Mr. Kellogg's book, the reader who wishes more detailed information about the characteristic soil types of a given area of the country, will find much helpful data in *Soils and Men,* the *Yearbook* of the United States Department of Agriculture for 1938. Still further detail for limited areas, such as counties, may be had by consulting the soil map, if one has been issued, of the county involved.

Our concern here is to determine how the soils we have damaged can be rehabilitated without our having to await the repetition of the natural processes by which they were originally created. Soil creation is, in nature, long drawn out. People now threatened by famine view with apprehension the supposed necessity for throwing our present de. pleted soils back into forest or grassland and waiting sev eral generations for the time when a new set of soils may be cleared. Just how the intervening generations can subsist in the interim is not at all clear. There is ample justification for the gloom displayed by many of our foremost students of soils. The present chapter is intended to mitigate the fears engendered by such cheerless forebodings.

The development of pessimism among soil scientists is understandable if one studies the history of thought on the subject of fertility maintenance as it has progressed in the past thirty years. This period has witnessed the most active efforts the world has yet known, chiefly here in the United States, to restore soil to its original ability to produce. A number of ideas helped initiate this wave of national interest in soil improvement. There is the established fact that rural population had been steadily declining while urban has been increasing. The prediction has been freely made that in a few decades the world's population may be too great for the food producing capacity of our soils. There has been the increasing conviction, too, that the science of chemistry might hold the secret of permanent fertility for the soil. Such influences helped to initiate government-sponsored agencies whose purpose was to inform farmers generally of the need for definite practices looking to soil improvement. Universally, the practices recommended involved cash expenditures at one point or another. Moreover, it soon became evident that the maintenance of fertility in soils which still produced fair crops is much easier to accomplish than the restoration of productive ability in soils which have lost all of their original black smudge.

For many years there was no means by which the government could assist farmers financially. In order for a farmer to do what was recommended, he must have either cash or credit. Multitudes of farmers who were greatly in need of assistance had neither. The result was that, without so intending, we developed a more or less stratified series of agricultural classes, with distinct tendencies to specialization, thus producing several "project" classes. Some general farmers became beef-cattle feeders; some became dairymen, some poultrymen, and so on. Many in each class retained a minimum of general farming practices while fully equipping themselves with the necessary mechanical accouterments of their specialty. Because of their progress in this direction, many farmers became more and more dependent upon other farmers and the urban population for necessities they formerly had provided for themselves. Thus a commercialized, not to say industrialized, type of farming was developed by those farmers who originally were able to follow the county agent's instructions.

While this grading up of a financially fortunate group of farmers was in progress, an equally effective degeneration was taking place among those at the other end of the scale. Men whose land, prior to the launching of the government's agricultural program, had lost most of its organic matter were already so hard put financially that they could not adopt the most important recommendations of their advisers. They were willing enough, but few of them had enough cash to enable their families to live comfortably, they could spare none for soil improvement.

Belated recognition of the necessary relation of soil degeneration to lack of cash for soil improvement resulted ultimately in the establishment of legal provisions for aiding distressed farmers in the rehabilitation of their lands. A number of agencies are now in position to assist such farmers, who can obtain loans for many projects for which money was formerly not obtainable. In desperately needy situations grants in aid can be made. In fact, so liberalized are the Congressional acts and the regulations for their administration that every conceivable condition of agricultural distress can be relieved through one of several agencies, provided it can be relieved by money.

It was not, and is not now, the intention of the government to expand the present programs to include all farmers whose land requires rehabilitation. So vast an undertaking would require more cash than the richest government in the world could scrape together by taxation. The hope is that private lending agencies in the localities concerned will take over the job for their communities. In fact, in certain areas this is being done in a small way. However, in the sections of the country where the need for soil improvements is most acute, the local banks, quite naturalIy, are in much the same poverty-stricken condition as their farmer customers. There is not, therefore, any very obvious solution for this paramount problem of soil rehabilitation.

There are, too, other aspects of the matter that must be considered. It must be admitted that the per acre cost of production is necessarily increased by any measure which requires the establishment of terraces or other means of controlling runoff water. Terraces are engineering projects, the cost of which on poverty-stricken acres can easily amount to more than the previous value of the land per acre. The construction of them might double the farmer's investment in his land without making a real start toward increasing its productiveness. And it must be remembered that, where the need for terraces is supposedly imperative, their construction must precede other conditioning of the soil. This subsequent conditioning usually requires applications of lime, the growing of legumes, the application of basic fertilizers, the addition in some instances of the so-called "trace elements," and such other expensive opera.tions as the rearrangement of fences, grassing or otherwise protecting the outlets for water, and so on.

The above paragraph includes much material for which footnotes might be in order. It will perhaps be more direct and helpful to refer the reader to the many government bulletins which give lucid explanations of the various steps in the conventional soil-improvement programs. A recent series carries titles which make use of the expression "Soil Defense," and a special bulletin is devoted to each import tent section of the country. For full information on the measures which officially are considered necessary in order to restore our badly eroded land to high production, the following bulletins, issued by the Soil Conservation Service of the United States Department of Agriculture, are recommended:

Farmers' Bulletin No. 1789, Terracing for Soil and Water Conservation;
Farmers' Bulletin No. 1813, Prevention and Control of Gullies;
Farmers' Bulletin No. 1795, Conserving Corn Belt Soil;
Farmers' Bulletin No. 1809, Soil Defense in the South;
Farmers' Bulletin No. 1810, Soil Defense in the Northeast;
Farmers' Bulletin No. 1767, Soil Defense in the Piedmont.

It is obvious that, at best, our conventional programs of soil improvement necessarily involve a cash outlay in almost all cases. The basic assumption that plant foods re.moved by crops must be replaced makes a virtue of the use of fertilizers and fertilizers cost money. Then there is lime, which in most situations is considered a prerequisite to the growing of legumes; and lime, too, is expensive to buy, and even more expensive to apply. Quite a list of recommendations could be compiled, one or more of which would be "must" requirements for every soil improvement project. And without exception there would be a necessary cash outlay involved.

As previously indicated, those farmers who have really received benefits from the past thirty years of intensive county agent work and the agricultural extension program in general have been helped because they were able to help themselves to some extent. They have spent a fair portion of their profits, too, in annual outlays for fertilizers, lime, legume seed, inoculating media, and so forth. As a result, the cost per acre of managing the land has increased considerably. This does not necessarily mean an increase in the cost per unit of the product. Rather, it is more likely to mean just the opposite. Hence, because of increased yields, these men have seemed to be justified in "plowing back the profits" in the manner described. The land has become more productive as a result, and is, therefore, more valuable land.

If we assume the continuance of the present agenda, it is apparent that those farmers who have been the chief beneficiaries of the extension program will continue to profit thereby, for they are best able to adopt any new recommendation requiring a cash outlay. Because this is so apparent, little thought is being given to ameliorating their situation. Under the present conventional way of doing things, these men are in the most favored position of any; so it would be considered foolish to worry about them when there are so many others in really serious economic difficulties. Nobody is worrying, therefore, about the present-day leaders among dirt farmers who seem so firmly entrenched.

It can now be said with absolute assurance that the supposedly safe position of our most progressive farmers is really destined to become the most precarious. The difficulty is the high overhead these men have developed. They have learned to make a profit on potatoes at 50 cents a bushel, for instance, they will be unable to come out whole, however, on potatoes sold at one half as much. Progressive farmers are geared to high production of a comparatively high-cost product. When their neighbors, who have formerly been too poor to comply with the ordinary requirements for soil improvement, find they can produce twice as many bushels per acre as most farmers grow--and can do it without any of the customary cash costs--the market for such crops will react downward in terms of price to the increased production. It is just this event that is going to prove the undoing of men who now are our very best farmers. In all probability the event will come almost unheralded, for the present agenda will probably continue to be taught for many years beyond the time when the first farmers begin to change over from plowing to disking. No important change in market prices will occur until there is sufficient volume of the new low-cost product to justify price reductions. The final result may be a debacle for those now in the most favored position.

Just how such men--at present the respected leaders of Farm Bureau activities, Grange work, and in many instances the chief support of agricultural "propaganda" of the government--will be able to clear their mortgages and emerge solvent from such an economic trap is not at all clear. It is difficult to understand how they will become aware of their plight until it is too late; for up to now (early 1943) no surface indications have appeared that any change in agenda is in prospect. There is evidence, however, that scientists of the government are quietly being prepared for what amounts to a plowless agriculture. The "house organ" of the Soil Conservation Service, *Soil Conservation*, has for two years been carrying articles showing the advantages of surface incorporation of organic matter. At least one committee in Congress has been made aware that a change is impending. A two-day meeting of scientific men and machinery manufacturers was held in Chicago late in 1941 at which the possibilities of designing implements for surface incorporation were discussed. The newly established soil and fertilizer investigations of the Bureau of Plant Industry presumably are to set up hurriedly the alleged experimental basis upon which the new agenda will be justified. All this is being done, presumably, without arrangements for rescuing the advance guard of the present regime when the new blitzkrieg of low-cost crops reaches the demoralized markets.

It may not be clear to the reader just how great the danger is. The average layman may not recognize the fact that there is no crying need for new machinery with which to effect the change from plowing to surface incorporation. That is lust the point. Only one thing is necessary in order to prepare for immediate realization of the benefits of the new regime. That need is the education of farmers to the error of plowing, and to the fact that a properly used disk harrow can completely prepare the land for crops. When farmers have been informed that they can actually mix tremendous quantities of organic matter into the soil with a disk harrow, that they can do it safely, without the backfire that always accompanies the plowing in of such materials, that they can then produce far better and bigger crops than they have ever seen or dared to hope for--then the majority of them will begin to check the new information by private experimentation. Thereafter, it will not be long until soil types and all of the expensive treatments that go with them will cease to be of importance. If the men who now are the backbone of commercial agriculture prove to be among the tardy ones to acquire the new information, it will be at their great cost.

Much of this chapter may have seemed a digression from, rather than a discussion of, the subject of soil classification. The reason is that we are discussing practical rather than academic matters. There can not be the slightest doubt that, when soils have been robbed of their natural mantle of organic matter, they emerge as divergent and dissimilar masses of minerals. Quite naturally, these varied areas of sand, clay, silt, or what not, behave differently when planted to various crops. Possibly, too, these same soils, when reclothed with plenty of well mixed organic matter, will yield varying amounts, because of the fact that they are of slightly different soil type. However, a difference of a few bushels per acre, when the average production is one hundred bushels per acre or more, is a less serious matter than when the differential is based on averages running between ten and twenty-five bushels per acre.

It is no credit to us, considering our mastery of machinery, that orientals produce four to ten times greater crops than we do on land which in some instances is inferior to ours. But they are doing it, and partly at least because they have grasped the true requirements of soil management. We should produce as much on lands now producing from ten to fifteen bushels of corn, for example, particularly in the humid areas of our corn belt.

With the exception of some bizarre types of soil like the ground water podzols, which carry their organic matter concealed by several inches of overlying sand, and perhaps other abnormal types of soil with which I am unacquainted, we ought to be able to excel any other people of the world in *production per acre* on most of the land that has been in crops in this country for generations. We have long been superior in *production per man,* because of our use of machinery. When we have begun to do by machinery what heretofore we have thought must be done by bugs and worms of the soil surface (the intimate intermixing of organic matter with the surface layers) we shall find ourselves automatically leading the world in *production per acre* as well. It is impossible now to foresee the economic changes which will necessarily follow this basic change in our relations with the soil. That they will be vast is certain.

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COALS TO NEWCASTLE

THE PROBLEMS connected with soil fertility are now very grave, yet future writers may find them not serious, but perhaps even amusing. Nevertheless, our present serious attitude toward these problems is fully justified, for too many American farmers, as well as their colleagues abroad, are at death grips with the economic problems arising from the mismanagement of the soil. However, when the existing unbalance has been adjusted and we are able to look back upon the scarcely excusable follies of a pseudo-scientific agriculture, it will afford us some satisfaction that, despite man's struggle for generations against odds of his own creation, he at last discovered the truth. We have been becalmed agriculturally, like the famous shipwrecked sailors--thirsty for days as they floated in the mouth of the Amazon.

Plenty of plant food is available in our soils. There is absolutely no need for commercial fertilizers. Nature can make available annually enough new plant food to grow crops several times as large as we produce now. Our present era of decreasing crops can be explained only by the fact that by plowing we beat into unproductive submission soils which, when not disturbed by man, produce a vigorous growth continually. We have known for a long time that the "upper six inches" of soil contain enough of the least abundant plant food elements to produce maximum crops for some four hundred years. How much greater quantity must be held in the successive underlying layers between here and China! There are infinite possibilities for high production by these soils that we have worn down. Modern man has not visualized the high yields that will spring from the soil just as soon as nature receives full cooperation.

In the past, we have believed that we were co-operating with nature, but we have not made use even of well-known facts that most high-school science students grasp early in their careers. Until we begin to put these principles to work, we can scarcely be said to co-operate with nature. Instead, we have been working at cross purposes with the design for growth through which all plants exist. It is as if we tried to feed fish in an aquarium by scattering food on the plate-glass cover.

Thirty years ago students of soils at the University of Kentucky asked why it is necessary to apply fertilizers to soil richly endowed with the very elements that fertilizers contain. The answer given was that the minerals of the soil are highly insoluble, otherwise they would not be in it. This sounded logical. We could understand that, if only one-fourth of one per cent of the relatively small quantity of phosphorus in the soil could he dissolved each season, crops might easily suffer, even though ample phosphorus existed in the soil. Thus we were satisfied by explanations which seemed reasonable, but which did not take into account the inconsistent thriftiness of the natural landscape.

Everywhere about us is evidence that the undisturbed surface of the earth produces a healthier growth than that portion now being farmed. Barring setbacks such as forest fires, trees in a woodland become sturdier every year, and each tree also adds a new ring of wood beneath its bark. The minerals of the earth evidently are available in abundance to these trees--more each succeeding season, despite the heavy tax of wood growth, the foraging by wild animals, and the other tolls which, all together, must equal or surpass the drain on plant food from cultivated land.

Innumerable buffalo, wild horses, wild cattle, goats, deer, and other animals fed upon the grasses of the plains. Millions of these animals were nourished by the vegetation on the untilled prairie land. In supplying food for this multitude, the underlying soil, through the use of the "insoluble minerals," developed a growth of grass which in many places would hide a rider on horseback. All this came without the help of man. No artificial fertilizer was applied; no plowing was done; no cultivation was undertaken--there was nothing whatever of the "advantageous" contributions man makes toward plant growth; yet on these plains was found the most amazing development of nutritious grasses the world has ever seen. We may well wonder just what help man does contribute.

We can recognize the fact that man at his best contributes nothing to the growth of plants; at his worst he rapidly destroys excellent growing conditions, under the delusion that he is nurturing his crops. Millions of farmers contribute to the soil food materials in the form of fertilizers and manures; but in their handling of the land they force the loss from the plowsole of many times as much as they contribute; so that the net effect of their well-meaning work is to deprive their crops of the sustenance which nature so generously provides for all plant growth. The net effect of fertilizing the land, then, is not to increase the possible crop yield, but to decrease the devastating effects of plowing.

The manner in which plowing robs crops of their rightful decomposition products has been demonstrated in previous chapters. Now it is time to show how the land, if left to itself, is capable of far better production than farmers ever get from it. By analyzing the subsurface physical, chemical, and biological conditions created by plowing, we are able to determine definitely just why the farmer has never been able to equal the natural landscape on land that had been allowed to deteriorate to any degree. This discussion is somewhat technical, but it is necessary for an understanding of the problem.

Conditions which favor decay are the same as those which favor the growth and development of those bacteria which are the agencies of decay. We know, of course, that nearly all decay bacteria are most active within a certain *temperature range,* with a certain degree of *moisture,* in the presence of a suitable *food* supply, and (depending upon the kind of bacteria) with either an *abundance of air* or a *restricted supply of air.* We know, too, that it would be difficult to imagine conditions better suited to encourage decay than are usually provided just under the surface of the soil. By plowing, the farmer places the decayable organic matter in the most favorable environment for prompt and complete decay. The organic matter itself is the *food.* The bacteria are always present in nature. During much of the year moisture and temperature conditions are within what bacteriologists call the *optimum range.* It is not surprising, then, that whatever the farmer plows into the ground can not be recognized a few weeks or months later. It has simply vanished through decay.

All decaying matter produces carbon dioxide, a gas which is heavier than air. The air in a well is displaced by it if something is decaying in the water. Carbon dioxide accumulates in the empty part of a half-filled silo. Many men have died in wells and silos because they did not know that this lethal gas lay below the air at the top. The smoke from a fire is chiefly carbon dioxide, but the heat of the fire provides the force necessary to lift it. In the absence of such a force, carbon dioxide *accumulates under the air, forcing the air upward.* Plowed-in organic matter, if in sufficient quantity, creates a zone of decay which is rather continuous and at approximately uniform depth. This decaying mass constantly releases carbon dioxide while decay is in progress. The carbon dioxide *must* fill the soil, gradually and completely forcing out the air which occupied the spaces between soil particles. There is no alternative, because there is no force, such as the heat of a fire, to remove the carbon dioxide generated at the plowsole.

That decaying organic matter must completely fill the soil with carbon dioxide has never been thought of as significant. Indeed, so insignificant has it seemed that the fact has never been emphasized in courses in soils. My test work in the field in 1940 showed conclusively that something important has been overlooked in this connection. There was irrefutable proof that my crops obtained their nitrogen almost solely from the atmosphere. This would not have seemed odd if the crops had all been legume crops, for the legumes have long been known to use nitrogen obtained from the air by the nitrogen gathering bacteria that become parasitic on their roots. However, the only legumes I had were green beans. My other crops were tomatoes, cucumbers, onions, potatoes, cabbage, and lettuce. All these crops, legumes or others, thrived equally well, although no nitrogen was used anywhere on the farm in that year. Moreover, the land was not capable of providing more than a small fraction of the nitrogen used, and the only organic matter supplied was the tall rye that was disked in. It is a well-known fact among scientific men that, if rye from three to six feet tall is plowed in, several weeks must elapse before it is safe to start crops in the land. Also, it is well known that, for rapid decomposition of such a mass of material plowed in, it is necessary to put in with it a generous application of nitrogen fertilizer. None of these requirements was met on my farm; yet every crop had all the nitrogen it needed throughout the growing season. Thus there was plenty of evidence that these non-leguminous crops had access to atmospheric nitrogen as completely as legumes produced under the most favorable conditions. Obviously, some unusual condition prevailed to make this true.

The only unusual condition was that all decomposition occurred in circumstances which provided an abundance of nitrogen continually to *saprophitic nitrogen-gathering bacteria* (which require no living host to provide them with the needed carbohydrates to supplement the nitrogen they get from the air). Since 1901 it has been known that such bacteria exist in the soil. Their ability to gather nitrogen under laboratory conditions has been proved conclusively in many laboratories, but these findings have gathered dust on the shelves because nobody had ever thought to force these bacteria to "eat"" organic matter in the open air. When decay occurred at the plowsole, nitrogen as a component of the air was excluded; therefore, these saprophytic nitrogen gatherers were denied their atmospheric nitrogen. It appears from my field tests that if the rotting of the organic matter occurs in the open air, these bacteria are just as efficient at gathering nitrogen as are their parasitic kin. Moreover, the nitrogen gathered has no chance to be lost; for the crop roots are present to make use of it as soon as the bacteria die and become part of the decaying mass. The crop plants get their nitrogen almost directly from the air.

This discovery means that hereafter no one needs to buy nitrogen as a fertilizer. It means also that no one needs to grow legumes in order to have the benefit of the nitrogen they accumulate in the soil. Furthermore, since lime is used on the land solely because it creates better conditions for growing legumes, there will no longer be a necessity for farmers to buy and apply lime to their soil. One small discovery, then, makes possible the discontinuing of a considerable expense in farming. Nobody is going to buy lime or nitrogen fertilizer, or grow and plow down legumes, when crops can obtain their own nitrogen from the air without this bother and expense.

This, however, is not the entire story. Crops cannot live on nitrogen alone. They must have in relatively small quantities many minerals which can be obtained only from the soil. The decay of organic matter plays an important part in releasing these minerals from the relatively insoluble crystals that have resisted weather influences since time began. Organic matter itself contains some of the minerals, which, as it decays, are released for the use of neighboring plants. In the process of decay carbon dioxide gas is released; and when it dissolves in water, carbonic acid results. Thus water and carbon dioxide together are carbonic acid, the best known natural solvent for plant-food minerals. Carbonic acid readily reduces to carbonates, or other usable forms, those minerals which in the presence of water alone dissolve very slowly.

When organic materials decay at plow depth, the water below the plowsole is prevented from moving into the upper layers of the soil. (This is especially true if the quantity of organic material is so great that it separates completely the subsoil from the topsoil.) As a result, the land quickly becomes dry and remains dry throughout the period of decomposition. Because the soil into which the carbon dioxide is discharged is dry, no carbonic acid is formed, and the gas eventually escapes from the mass of minerals without having contributed to the release of mineral plant foods.

In disked soil the situation is quite different. Water from deep in the earth can rise to the soil surface, or until it is caught and absorbed into organic matter. Because the movement of water in the whole mass of soil is unrestricted, there is always water present (at any time when decay is possible) to dissolve the carbon dioxide gas given off by the decay. No carbon dioxide escapes from the soil, and most of it becomes carbonic acid. This acid releases for the use of adjacent plants the otherwise adamant minerals which are so badly needed by farm crops. By this simple and well-known chemical action in the soil, the organic matter itself goes a long way toward providing the minerals which otherwise the farmer must buy in a bag.

Can decaying organic matter in the surface of the soil release enough minerals for maximum crops? The answer seems to depend altogether upon how much organic decay is in process during the growing season. I can not state whether maximum crops can be expected from land into which great quantities of organic matter have been disked--without the application of artificial fertilizers. I feel sure, however, that very early in the process of rejuvenating soil by restoring organic matter to its surface, farmers will discover that no application of fertilizer, however great, results in an increased crop yield. This opinion is based solely upon experiences and observations during strictly unofficial tests. It seems entirely reasonable to expect that the quantity of minerals released during any growing season wil be sufficient to produce maximum crops, providing the volume of carbonic acid formed by decay is adequate.

It may be suggested that--judging from experience, again--what we now think of as maximum crops will be badly dwarfed by the actual results that will follow the disking of important quantities of organic matter. I have already produced crops in excess of one thousand bushels per acre under such conditions as I am describing, without fertilizers or any soil amendment other than plenty of organic matter.

When farmers and scientific men begin to experiment with this plan for the growing of crops, they will be surprised and disappointed at the appearance of the plants during a considerable portion of the growing season. Crops that are destined to produce two or three times the customary yield will look as if they could scarcely produce an average yield. The color, during dry, windy weather especially, will not be the dark, lush green that we have been accustomed to associate with healthy crops. Even in moist, favorable periods crops grown without the use of nitrogen fertilizers will be quite ordinary in appearance. Many a farmer, when he observes this absence of dark green color, will want to crowd the crop by the use of nitrogen fertilizer. However, if he is wise, he will wait patiently to see what the outcome will be without nitrogen. That outcome will please him beyond measure, considering that all his past experience will have taught him to expect a short crop. When he discovers a big increase in yield, he will be entitled not only to wonder why, but to analyze his results.

The explanation of this strange phenomenon is simple. For as long as most men now living can remember, fertilizers have carried some nitrogen. The nitrogen in early fertilizers designed for staple crops was usually not more than 2 per cent--forty pounds to a ton. At the usual rate of application of fertilizer, at most two hundred to three hundred pounds per acre, this small application of nitrogen, four to six pounds per acre, could do nothing more than "advertise" the fertilizer by keeping the crop dark green until hot weather came. Then, the rapid loss of color would be charged against drought or some other circumstance. We may conclude, then, that our judgment of a healthy green color has been warped by our fertilizer experience.

Experienced farmers and scientists know that if a crop grows too luxuriantly in the early weeks, when there is plenty of water, it is likely before harvest time to encounter weather conditions which will make such growth difficult to maintain. Such events precede the firing of corn blades. Often, when the farmer has overdone nitrogen feeding at planting time, the rainfall will be sufficient for a few weeks to induce extraordinary growth. The almost inevitable sequel is dry weather, which suddenly stops the liberal flow of nutrients into the plant. Retrenchment in the form of dead leaves--so that the available nutrients can support the remainder of the plant--is a forced procedure. Fired corn blades, therefore, are no mystery, but should be expected as a result of certain fertilizer practices.

There is plenty of nitrogen in the air; there are practically unlimited quantities of mineral nutrients in the soil The new practices make it possible to utilize natural forces to make these available. Therefore, we should hereafter stop carrying coals to Newcastle, by fertilizing soils that already have an abundance of plant food.

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EXIT PESTS

THE HYPOTHESIS that environment influences plant disease and insect damage is not new. In early agricultural literature, writers generally accepted the theory that the better the growing conditions for plants, the less the risks from disease and insects. From 1910 to the present time, however, it has been difficult to find this theory expressed in writings on agricultural subjects.

It is true that the era of soil depletion has been contemporaneous with the period in which diseases and insects have become most troublesome. This could be true, of course, without being significant; but there are very good reasons for supposing a connection to exist. Many farmers can remember when there were no Colorado potato beetles, San Jose scale, and other insects and blights now common. These same men can remember also that at that time their plows separated a zone of almost black upper soil from the yellowish subsoil. This black topsoil has now disappeared; at the same time many new insects have made their appearance, and those that were present before have become much more numerous. Plant diseases have multiplied in number and increased in virulence during the same period. We may well ask, then: Is environment (meaning the soil) a factor in their control?

Certain human and animal diseases and parasites have long been thought of an environmental. Hookworms belong entirely in the South, particularly in the southeastern section of the United States. Malaria can occur only where the Anopheles mosquito is present. Pellagra and other so-called deficiency diseases have usually been thought of as belonging to certain localities. It has not been difficult to connect such troubles with the environment in which they have been found.

In recent years the control of deficiency diseases has been much improved in most areas because of the more general availability of protective foods. Coincident with this improvement, however, there seems to have been a general decline in the nutritive value of foods produced on average land. The discovery of vitamins has brought this matter into better focus. When knowledge of vitamins was new, it was thought that certain foods contained an abundance of particular vitamins. Egg yolk was said to be rich in most of them. Now it is known that the vitamin content of the egg yolk is seriously affected by the food consumed by the hen. Butterfat was considered to be uniformly potent as a source of vitamin A. hive recent discoveries show that the vitamin content of butterfat or cream is largely dependent upon whether or not the cow has access to a quantity of grass, or to the richly colored foods which provide her with this essential vitamin. Neither the hen nor the cow can by herself create the various vitamins she transmits to the consumer of her products. The vitamins must be supplied to each animal through food.

These disquieting discoveries--that foods we had thought were always richly endowed with health-giving substances may themselves be deficient in certain instances--have shifted attention to the plants. which normally would be expected to supply vitamins to the animal. It becomes a complicated chain of cause and effect: milk--cow--hay, grain, or grass--soil. In other words, the blame for any deficiency goes back, in the last analysis, to the soil.

Then we discover that during the very period in which deficiency diseases are being decreased in the localities where they have been most serious, the area in which they occur seems to be widening. In the last few years certain of the deficiency diseases have been found in places where they were unknown before. And, at the very same time, we find that the soil--life's ultimate source--has declined sharply in its ability to nourish properly the plants upon which we depend.

Characteristically, Americans confronted by this dilemma of deficient foods have turned to the drug stores to buy vitamins. There is little doubt that the development of synthetic vitamins has served to postpone disaster for many people; but it seems unnecessary to pay for something whose value is not yet wholly unquestioned, when by properly modifying the environment in which our plants live, we can again build into our food plants all the vitamin richness they once had.

The logic of such a viewpoint is inescapable, yet it has not been investigated officially to determine whether it may be true in fact. We have experimental data to prove the necessary casual relationship between the completely nourished cow and the milk rich in vitamins and other nutrients. We know through experiment that only good feed in correct proportions and quantities can nourish the cow properly. We are just as sure, with ample experimental proof to sustain us, that only a soil that is capable of supplying a sufficiency of plant nutrients in suitable combinations can create foods richly endowed with the elements needed to produce human or animal health. We have, in other words, all the necessary elements of logic for reasoning from the good soil to the best of health, or from the poor soil to the direst of disease in the animals which consume the products of the soil, but we have not assembled those elements into the necessary whole to arrive at the logical conclusion. Our agricultural reasoning is in much the same condition as was the passenger transportation of the country before the existing railway lines had been grouped into great transcontinental systems. We should be able now to take the entire "trip" from starting point (good or poor soil) to terminus (good or poor health) without having to make the local stops.

In my test work and, subsequently, in field work, I discovered that soil conditions seemed to be factor) in the extent to which plants were affected by diseases and insects. The evidence was so convincing that I watched carefully for verification of the idea in commercial crop growing when the tests were repeated on a field scale. The results ;n the field fully confirmed the earlier deductions. I am sure that the existence or nonexistence of plant diseases in certain fields is related to the condition of the soil, and that the incidence of insect damage is likewise related. No other conclusion seems possible from the amazing behavior of insects and the absence of diseases in the crops I grew on land which had been prepared by disking in (or down) great quantities of green manure crops. Yet, despite this existing chain of experimental evidence proving the truth of every element in the necessary reasoning, we can not accept such an unofficial decision as true until it has been proved so by properly supervised official tests. For such tests we shall look to the experiment stations which have been established for that purpose.

While the presence or absence of insects or diseases seems not to be necessary to this reasoning, an important purpose wilt be served by dependable knowledge of just how completely their behavior indicates the suitability of the soil in which the plant is growing. If insects and diseases prove to be a perfect index, as they must if they are truly environmental, then an entirely new "soil-testing" method becomes available to the farmer. Whenever his crops become infested by insects or are attacked by disease, he may know immediately that further green manure treatment will be helpful.

Since in ordinary farming and horticulture the fight against pests of all kinds has partaken of the inevitable, how, it may be asked, can a method of soil preparation possibly result in a change for the better? I had to find an answer to that question before I could accept the idea. The answer was difficult to find. No official experimentation by soils experts had been carried out on land prepared by surface incorporation of great quantities of organic matter. All experimental plots had been plowed, if there was much organic matter to be disposed of. Disking has been considerable feasible only where there was little trash or crop debris involved. Experiment station results, therefore, supplied nothing directly bearing on the case.

To me it seemed necessary to assume that the soil in which organic matter in great quantities was decaying would be richer by the quantity of decay products that had been accumulated in it. As organic matter decays, soil minerals are released, as are also the additional elements which make up the organic compounds of which the living material had been composed. Depending upon the character of the organic material, decay may take place quickly or slowly. In either case, unless there are roots present at the time the decay products are set free, these used plant foods are almost certain to be flushed out of the soil by the very first rainfall. The only certain way to prevent this loss is to have roots of growing plants always present when decomposition is going on in the soil. On land that is left undisturbed, nature takes care of this. Roots are always present; therefore, no plant food is leached away.

On the farm these salvaging roots may be those of beans, cucumbers, or any other crop the farmer wants to grow. The roots of such crops will gratefully absorb all the decay products they can get. It is a reasonable assumption that the soil solution these roots pick up from decaying organic matter is different from that they would find available in pure mineral soil where nothing is rotting. Decaying material in the soil enriches the soil solution, so that each unit of liquid can supply several times as much plant food as the same quantity of water from soil not enriched by decay. That is only common sense.

It follows that the more decaying material there is in the soil, the richer the solution these roots pick up will be; the richer the soil solution carried in by roots, the richer in minerals the plant sap will be. From this point it is easy to assume that variations in the richness of the plant sap may affect the attractiveness of the plant for its customary parasites. A greater proportion of minerals in the sap may result in its carrying less sugar, and a decrease in sugar content may easily make the plant sap distasteful. Possibly cucumber beetles, for example, could be starved for lack of palatable juices, even when their host plant is enjoying the richest possible food from the decay in progress in the soil.

Such a theory is not entirely without foundation in science, even though no specific research has been devoted to it. We do know that variations in internal juices of plants are produced by variations in the fertilizer treatment and in the available moisture of the soil. This fact was established in 1918 by Dr. Kraus and Dr. Kraybill, whose report has been used by a generation of students as a reference work in horticulture. [E. J. Kraus and H. R. Kraybill, *Vegetation and Reproduction, With Special Reference to the Tomato* (Oregon Bulletin 149,1918).] There is no question that changes in plant composition are produced by changes in the nutrients available in the soil. We can not, of course, know how insects feel about having their favorite host plants overfed on minerals that originate from decay. We can only guess, from the fact that they prefer the scantily fed plants to those that are better fed, that the richer sap is less palatable to the insect.

If this theory is tenable, the human race is extremely fortunate. It becomes possible, because of this relationship between the insect and its food supply, to improve the human food supply by the very method that will starve the insects.

Apparently diseases yield even more completely to the environmental conditions which are most favorable to plant growth. I am unable to advance, as tenable, a reason for this. It appears, however, that the leaf surface of fully nourished plants is better fortified to prevent the entrance of infections. That there is a difference in texture of the leaf surface of well-nourished plants compared with those growing on thin land may easily explain their better resistance to disease. In this connection, the natural resistance of healthy, well-nourished plants becomes entirely logical.

It is reasonable to believe that insects and diseases thrive only in a suitable environment, just as do other living things. Further, it appears that the environment that is best for the disease and the insect is poorest for the host plant; and the conditions that favor the host plant's development are intolerable for insects and diseases.

Scientific men with whom I have discussed this theory are not inclined to agree, because they still think the type of soil would be an important factor and doubt that the experience would be the same under other soil conditions. My contention is that the one determining condition is the surface incorporation of great quantities of organic matter, that any type of soil so treated would bring similar results--provided other conditions were no less favorable than they were for my 1940 tests. (It can be said truthfully that the seasonal conditions from July 12, 1940, to frost were such that many other plantings of beans had to be aband oned in the neighborhood where my beans thrived.)

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WEEDLESS FARMING

I AM FULLY AWARE that it seems fantastically improbable to say that we should ever be able to farm land without trouble from weeds. Weeds have been keeping farmers busy for so many generations that they are taken for granted. In all of our farm planning, we have regarded weeds as a necessary evil; and moralists may even consider that weeds are a blessing, for the work necessary to check their growth keeps farmers out of mischief.

Thus unthinkingly we have accepted weeds as inevitable. But perhaps they are not inevitable. Perhaps they may be more vulnerable than we think. Like every other living thing, each individual weed must die at some time. None is everlasting, although there are some species which survive several years when undisturbed. In order to perpetuate itself, every species must have the opportunity to reproduce. If reproduction is prevented, the species can be eliminated.

It so happens that the majority of weeds that give trouble on farms are annuals; that is, they must originate each year from seeds produced by a previous generation. Since these annual weeds must propagate each season from seeds, it is obvious that the surest method of eliminating them from farm land is to prevent them from reaching maturity. The next season there can be no successors to those that were disposed of before they had borne mature seeds. Nobody will disagree with that statement, but everybody knows that the problem is not as simple as that, regardless of how logical it may seem. We all know how faithfully farmers work year after year to keep their land free of weeds; and yet weeds are perpetuated on the land of the most careful farmers.

Even this situation, however, is not as mysterious as it has always seemed. Without realizing what we were doing, we have buried weed seeds for future recovery every tune we have plowed the land. This statement may reveal the secret of weed perpetuation. We can cultivate a corn field as long as the cultivator can pass over the corn without damage, but we must stop as soon as use of the cultivator would break off the stalks. After the cessation of cultivation, there is a period of several weeks during which any weeds that have been missed in the cultivation can mature. All such weeds bear seeds. In addition, there are apt to be seeds--brought by that final cultivation into a position suitable for germination--that will germinate, and produce more seeds in the half-light of the shaded cornfield. There should be less mystery about how weeds manage to perpetuate themselves when we realize that they do their most effective work in a field after we have stopped trying to fight them.

If the land is plowed after the corn has been harvested, millions of weed seeds per acre may be hurled by the plow; but seeds that were buried by a previous plowing will be brought to the surface. Perhaps the weed seeds brought back to the surface this time will be those that were plowed under three years before after the last hay crop was cut. Although the land lay "idle" after the hay was harvested, it was producing ragweed, pigweed, smartweed, foxtail--a dozen different kinds of annual pests of cultivated fields. The seeds, after three years of burial, are now ready to germinate; and the plants they produce will create the necessity for cultivating the corn that is to be planted.

Thus, every time we plow the land, we create a new reserve of buried weed seeds which, at the next plowing. we resurrect. A vicious circle results. As long as we continue our present system of plowing the land, unless we adopt drastically different weed-control methods, we are continually undoing, at each plowing, whatever good work we started after the previous plowing. Again it may be said that we are the victims of our own system of handling the land.

Such conditions need not continue. Indeed, we can arrest rather abruptly the propagation of annual weeds in our fields if we will not alternate the base of operations every few years. By refusing to disturb the seeds which we buried at the last plowing, we will avoid creating the conditions favorable to their germination. Those seeds, on the other hand, which are placed in favorable position for germination by the act of disking in a green manure crop may be controlled with reasonable ease.

It must not be assumed, however, that a single field, properly handled with reference to weed control, will eliminate the possibility of weed growth, for seeds and fruits are wind borne in many instances. Success thus presupposes the application of controls by farmers generally over a considerable area. For the same reason, school lots, public lands, and all other similar holdings must not be left out of account. Weed control on a single plot will show very positive results, but as long as surrounding plots are contaminated to any considerable extent the labor of eradication must be continuous.

Here are my suggestions for eliminating weeds:

Seed the land to a green manure crop: rye in the fall or a suitable summer crop in the spring. Let the green manure crop grow until it has reached the proper height to be e worked into the soil with the available equipment. If weeds growing in the green manure crop begin to bloom, it is important that the crop be put into the land immediately. However, few weeds mature quickly enough to rush the incorporation of the green manure. Under almost all ordinary farm conditions in the humid section of the country, it will be possible to grow a winter crop and a summer crop, put each into the soil with its accompanying immature weeds, and in a short time bring about fertility of the soil and at the same time help rid the land of the weeds that create the necessity for cultivating farm crops.

In this discussion rye has been mentioned prominently and often—not because rye is the only crop for green manure, but because it is more suitable for a largr area of the country than any other winter-growing crop. Many other crops may be used with equal success. In sections where other crops are as good as, or better than, rye, such crops should be used. Summer crops. too, can be varied to suit the climate or the farmer's pocketbook. If a farmer has millet seed, it would be poor policy for him to trade it for soy beans for use as a summer green manure crop. It should be remembered that when these green manure crops are disked into the land instead of being plowed in, they are able to use air nitrogen just as well as the legumes do; therefore, there is no reason to prefer a legume for green manure. If the farmer has no seeds of any kind and the land is covered with weeds he can disk them in before they are mature and thus have adequate organic material. Anything that will rot will be advantageous when disked in and will improve the soil for the production of the next green manure crop.

It is impossible to determine in advance how many crops will have to be put into the soil before the land will begin to look black again; but disking ought to be continued until that point is reached. A rapid succession of summer and winter green manure crops should be used until the soil becomes highly granular and absorbent. It is difficult, also, to predict how many crops of immature weeds will have to be put into the land before the green manure crops will be free of weed growth, but the desired condition will be realized eventually. Inasmuch as the same few inches of soil are affected by each successive disking, every weed seed native to the soil zone chosen will finally have sprouted. Thereafter weeds will be produced only by those seeds which are wind borne or transported by other means to the area under treatment.

The eventual elimination of much farm work can be predicted on the assumption that weeds can be controlled. If weeds can be so controlled that the farmer's crops are not forced to compete with them for the plant food in the soil, then it goes without saying that no cultivation should be undertaken. There are important reasons for this, the most obvious one being that, since plant roots tend always to develop very near the surface of the soil, cultivation can not be accomplished without cutting these roots. Destruction of plant roots is definitely not beneficial to the plant itself; therefore, if the plants are free from weed competition, to stop cultivating farm crops will be mandatory.

Crop rows are customarily spaced three to six feet apart, partly to permit the destruction of weeds that spring up between the rows. If few weeds are going to spring up, then it is obvious that the rows in which crops are planted may be spaced as close together as the supply of available food in the soil will permit. Ordinarily plants are placed closer together in the row than the rows are placed to each other. Potato plants are usually placed twelve to eighteen inches apart in the row, but the rows themselves are three to four feet apart. Without weeds to interfere, potatoes may just as sensibly be spaced eighteen inches apart each way. The ideal arrangement would be to space the plants close enough to each other that their roots would completely occupy the intervals. (his would prevent the loss of nutrients which otherwise would be released by decay into soil unoccupied by roots.

One important fact deserves consideration at this point. Living plants require in their growth, and their dead bodies contain in their substance, only about one-tenth as much material by weight from the soil as they do from air and water. The contribution of the soil, then, to 100 bushels of corn weighing 5,600 pounds would be only about 560 pounds. Even if the entire 100 bushels were produced on one acre, the grain itself would take from that acre only 560 pounds of material. If 100 bushels of corn should be burned, the resulting ashes would weigh about 560 pounds. Therefore, it is evident that the growing of crops can not be unduly wearing on the land. If, as indicated in Chapter 11, we can use soil acids formed in the decomposition of organic matter to obtain minerals, and the native bacteria of the soil to pull in nitrogen from the air, the production of crops several times as abundant as we have grown is just a matter of sensible technique. Properly handled, farm land can be just as self-sufficient as the soil of the natural landscape has always been, because, when properly handled, farm land will be maintained in approximately the same physical condition as soil always is in nature.

The theories presented in this chapter have not been fully demonstrated, but experiments are under way at the present time to test the truth of the statements. No prediction can be made now as to when the experiments will be completed, since there is no basis for knowing positively just how long a time it will take to empty the upper few inches of soil of its stock of weed seeds, or when the soil will begin to look black again. My guess it that two to five years will be necessary. In the meantime, the succession of green manure crops will be planted twice a year and disked in before the weed seeds have matured. Then we shall be in a position to speak of the "when" as well as the "how" of weed control.

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MOTHER EARTH CAN SMILE AGAIN

IN THE PRECEDING CHAPTERS the moldboard plow has been shown to be the villain of the world's agricultural drama. Here in the United States it is suspected of wasting from the plowsole enough plant food to sustain crops with which to feed half the other peoples of the world--a suspicion based upon official reports. Elsewhere the record is less clearly defined; for nowhere else are moldboards of the sizes common in the United States in general use. The "bigger and better" the plow, the more devastating its effect.

When this appraisal of the plow has become official, as eventually it must, American agriculture will undergo drastic revision. It is hardly possible to make a blueprint, or even to hint at one, in terms more trustworthy than the usual perspective of greener pastures elsewhere. In this spirit, therefore, I undertake now to forecast some of the changes that are likely to result from the new agricultural scheme.

The pastures of the land will be greener, literally; crops will grow in better fashion, with immeasurably less attention than they have customarily been given in the past, the vitamins and minerals our foods used to contain in abundance will again be present in similar measure, and in consequence we shall undoubtedly be healthier, some of the tensions of civilization will be relaxed, and our lives should be more comfortable.

This is the favorable aspect of the picture. That the benefits will not be the same for all people, especially in the initial phases of change, is a perfectly admissible deduction from history. Technological change always brings temporary maladjustments; from the individual stand-point, they may even be considered disasters. Thus, when we begin to apply our new agricultural principles, which acknowledge the co operation of the eternal forces of growth against which we have hitherto been working, many people will be adversely affected. The position of some of them will be made almost completely untenable, until the wisdom of government has found a satisfactory solution.

The swiftest and most perceptible disturbance will occur in the economic field--specifically, the price structure of unprocessed farm commodities. As soon as crop yields several times as great per acre as our customary averages begin to come into the world's markets, prices will decline. This does not mean necessarily that those who practice the new agronomy will be the losers; their cost of production will be so low that their position will be greatly improved. It does mean, however, that those who do not take advantage of the new methods will suffer, and those who are now considered marginal producers will lose out entirely.

Moreover, renewed thought will have to be given to the so-called economy of abundance. There is such a thing as an upper limit to the amount of food that can be consumed by the population of the United States and by the now undernourished populations elsewhere in the world. For this reason, as the new methods of agriculture are applied generally, it may be found necessary to reduce the acreages devoted to staple food crops. It is not at all unlikely that the farmer whose land produced five times as much the first year, under the new methods, may realize a tenfold increase the second on the same land. Such possibilities preclude any prompt and completely effective economic curbs by acreage reduction. What would the farmer do with the acres withdrawn from the production of the given crop? Up to this time he has been told to devote the surplus acres to land-improving crops. If the basic principle of the new agricultural method proposed in this book is recalled, it will be clearly seen that the older methods of land improvement do not apply. Hence the impasse that appears when we resort to traditional methods of meeting the threat of crop surpluses.

Part of the result will be that the chemurgists are given an opportunity to take over and find economic uses for large areas of land that will not be needed for the production of food crops. Since, under the methods proposed in this book, the land so utilized will produce raw materials for the chemurgist at a mere fraction of the previous cost, vast opportunities are open to those who perfect and bring into production the countless products and commodities for which there will be a ready market among producers and consumers of fabricated goods.

In this connection, it must be remembered that we have literally been living on borrowed time. Consider the rate of the use of forests. If we have used far more timber than nature can allow us for such traditional things as we know, it is likely that the new uses which have been developed in the last ten years will exhaust our available timber at an even greater rate. The outlook for wood plastics is very intimately connected with the prospect that, under newer agricultural practice releasing land from food crops, we shall have areas which can profitably be returned to woodland.

Petroleum reserves, too, have been distributed with a lavish hand. That our large coal reserves might supplement our dwindling oil reservoirs is scarcely as happy a thought as possibility that surplus lands may be used for the production of materials easily distilled into fuels. And from this comes the easy corollary that the waste products from the refiner's retorts might be restored to the land as fertilizer. We should then experience a condition which the world has never before known in connection with the land--soil cropped annually without loss of virtue. For it should be clear by now, from the contents of this book, that cropping can build soil instead of destroying it.

Other influences will operate to modify the American landscape. With the invention of suitable mechanical equipment for use by the suburbanite in coaxing from his home site the foods his family needs, a gentle transformation of urbanities into suburbanites may be expected. There is nothing new about this, of course, except that what has heretofore been a fancy which could be indulged only by the well-placed may be open to the many. Thus, the decentralization of populations, urged for reasons of individual health and efficiency by industrialists and for reasons of defense by military authorities, may well become a reality. The beneficial effects on American civilization are sufficiently apparent to obviate discussion of them.

It is not enough that we should have in prospect supplies of food which would eliminate man's historic worry about shortages. With cheap production of foodstuffs, we should be able to look forward to the lowest-cost standard of living of the world. We have hitherto boasted of the "high standard of living" in America, but we have neglected to interpret that claim in the light of what our achievement has cost us. Food and other products of agriculture have figured prominently in the high costs of our present living standard. There is an intimate connection, moreover, between the cost of man's bread and the cost of everything else he produces. Despite the rejection by economists and humanitarians (and justly so) of the so-called subsistence theory of wages, perhaps insufficient thought has been devoted to the disproportionate expenditures for the products of the soil and the relation of these to costs of operation in every other field of human activity.

If all the other benefits to be derived from a revitalized agricultural method could be dismissed, the one which would attract us still is the physical well-being of man him" self. Foods are the sources of the vitamins, proteins, carbohydrates, and minerals by which man lives. He thrives or he fares ill in proportion to the availability of these essentials in the foods which are supplied him from farms and gardens of the land. Agronomists as well as nutritionists are aware that lands which have been exhausted of their essentials produce foodstuffs which are deficient in the end products required by human beings. It is not too much to expect that, by the restoration of the vital ingredients needed by our lands for the production of lush, vigorous, healthy crops, the vitality of man himself may be enormously enhanced, his deficiency diseases greatly reduced or eliminated, and his life expectancy increased. This result, if no other were envisaged, would be adequate justification for a "new" agriculture which is in reality very old.

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