SOIL AND CIVILIZATION

A Modern Concept of the Soil and the Historical Development of Agriculture

BY

MILTON WHITNEY

CHIEF, BUREAU OF SOILS

U. S. DEPARTMENT OF AGRICULTURE

ILLUSTRATED

LONDON

CHAPMAN & HALL, LTD.

11 HENRIETTA STREET, W. C. 2

1926

SOIL AND CIVILIZATION

PRINTED IN THE UNITED STATES OF AMERICA BY
THE PLIMPTON PRESS NORWOOD MASS.

PREFACE

A Concept of the soil is a picture or an image such as the artist might see and place upon canvas or the sculptor work out of a piece of marble. It is like an architect's concept of the great building which he sees before he begins his plans. The plans may need to be changed and modified in detail as the building proceeds. As the plan itself is not the building so this concept of the soil is intended to convey a picture which is to to be worked out and materialized as the work proceeds. Analogies and illustrations are freely used to bring out the meaning, just as symbols are used in the building plan to represent brick, tile, wood, steel or cement. They are not the real things, but they are the best means available for the architect to convey his idea of the completed structure and the relation of its different parts before the material building is developed from the plans, so that all of those who participate, either in the furnishing of money or labor, can better see the rôle they play and can more intelligently perform their part in erecting the edifice.

This concept of the soil is in nontechnical language that will be understood and should be interesting to all readers. It covers neither descriptions of methods of soil investigation nor practical methods of cultivation or other field operations which are to be found in numerous text books.

This is followed by a description of the important soils of the United States which it is believed further illustrates and defines the concept. This is in turn followed by a short chapter describing the principles of the methods of soil control.

The historical part of the book from the Development of Man on the Earth through the Agriculture in the Older Countries of the World and the Renaissance of Agriculture follows, for the information it has in support of the present concept of the soil in its different parts. This arrangement is considered preferable to beginning the work with the historical features as tending to make the presentation somewhat stronger and much more interesting. The concept is not derived from the historical narratives herein given but from the scientific investigations of the past 100 years, yet it must harmonize and cover the essential historic facts.

Jan. 2, 1925.

CONTENTS

ILLUSTRATIONS

FIGURE

SOIL AND CIVILIZATION

Chapter I

A MODERN CONCEPT OF THE SOIL

The Man

It may at first sight seem peculiar to begin a book on a Modern Concept of the Soil with a chapter dealing so largely with man and his qualifications. Upon second thought, however, such an introduction appears perfectly logical, for to supply the present needs of society the soil without the man is like a horse without a rider or a ship without a navigator,

"Useless each without the other."

The failure to maintain an average crop yield over a period of years is ordinarily laid upon the soil. As a matter of fact, a crop of corn or cotton is a product of the joint efforts of a man and a soil. Such a failure, therefore, may be due to the man or to the soil or to their joint effort, in which last case the blame is upon the man for he is the intelligent and directive head of the partnership. The failure on the part of the man may be due to the fact that he has selected a soil unsuited to corn or cotton or any other crop he selects; or having selected a proper soil he may have failed to understand or handle the soil intelligently.

We shall see in subsequent chapters that the soil is not the dead, inert, and simple thing often referred to as "dirt." It is essentially a factory where raw materials are converted into finished products. All factories must have intelligent care in all their parts and be fed regularly and intelligently with their raw materials to maintain their efficiency. A man who understands and can take charge of a chair factory can not be expected to handle as efficiently a silk factory. The soil may be likened unto a highly organized engine which must be cared for in all its parts to maintain its efficiency. A man who has been trained to handle a hoisting engine can not be expected from this training to handle efficiently a locomotive engine or a marine engine. Lastly the soil is a living thing, having many of the characteristics of an animal and requiring the same kind of intelligent and sympathetic care as an animal to keep it in condition to give the most effective service.

When a soil is referred to as a tool in the hands of man to accomplish something with, it is not as a simple tool such as a saw or plane, but as a highly organized tool as a factory or an engine or an animal.

Soil types differ in their character and in their ability and capacity to perform service, just as factories and engines and breeds and classes of animals differ. They each require different care and treatment, and it is upon the recognition and use of these differences in capacity and treatment that ultimate success depends.

It takes a man of considerable training and experience to run any kind of a factory, or any kind of an engine, or handle any breed of cattle efficiently, as it does to mine coal or lay bricks or shoe a horse or manage a store or a business of any kind. The soil is no less simple than these, and it requires years of training and experience to get the most out of each particular soil type.

It is true that under our present system of agriculture almost all crops are grown on almost all types of soil, but we must remember that the art of agriculture, the oldest and most fundamental of all the industries, is the least developed. We must remember on the other hand that the development of our other industries, including transportation, clothing, foods, metals, manufactures, our business organizations, commerce, our professions, including medicine, surgery, chemistry and electricity, have been developed within comparatively recent years and have a start over agriculture of perhaps 150 years. This means literally that at the time of the signing of the Constitution of the United States the industries and professions above named were no further advanced than agriculture is to-day. It implies, furthermore, that agriculture will advance in the future as other industries have advanced, and the object of writing this work on the Modern Concept of the Soil is to lay one fundamental concept before the people in the hope that it may encourage the serious and thoughtful study of the soil as an aid in the intelligent advancement of agriculture.

Nowadays when a man takes up a profession or an occupation he selects tools suitable for his needs. A lawyer acquires a set of law books, a physician a set of medical books and instruments suitable for his particular line of practice. It would be absurd now to say that a carpenter does not select the tools of a dentist nor the surgeon equip himself with the tools of a blacksmith, but it would not have been very absurd to make such a statement two or three hundred years ago, when there were no well-defined professions or occupations. A mechanic selects tools adapted to the particular kind of work that he is called upon to perform and often his success depends upon his ability to use the proper tools in a proper manner. We now expect a mechanic not only to have the proper tools but to have experience in the use of these tools that will insure his success in his vocation.

Even in agriculture at the present time in selecting a man to take care of a herd of cattle one looks for a man who has had experience with that particular type of animal. A man experienced in the handling of the phlegmatic Holstein dairy cow can not be expected to be equally satisfactory with the Jersey cow with its quick, nervous temperament, and still less can we expect a man who has had experience only with beef cattle to be successful with dairy cows. A man who has handled the Percheron draft horse should not be entrusted with the care and training of the thoroughbred race horse. In many specialized lines of agriculture such as tobacco growing, fruit growing, and truck growing, we require men of experience in these particular lines.

In general agriculture we in this country are not so particular, and indeed we seldom bother ourselves about the kind of experience a man has had with a particular soil type upon which he locates, nor does the man himself seem to appreciate that the character of the soil or the soil type has any particular significance in his farming operations. The Census of 1910 showed that 54 per cent of those on farms at that time had not been on the same farms more than 5 years. Within five years, which is not much more than a single crop rotation period, a man can not be expected to have acquired the intimate knowledge and experience requisite to the intelligent care of a soil type. What a lesson of inefficiency this conveys of failure to make good on the land he has left or the desire to win increased profits from other lands of which he knows not or of necessity driving him from pillar to post in an effort to gain a livelihood in one way or another. Very different are the experiences and customs of the older countries of Europe and of Asia. In Germany a man who has had his training on sandy soils would not willingly be taken onto a farm having a clay soil or a moor soil. Germany produces about 30 bushels of wheat per acre while we in this country with our methods produce on an average about 16 bushels. The world renowned English gardener has been on the same land all his life and his father and his grandfather on the same type of soil. He has inherited knowledge and experience of many generations on the same type of soil. The Japanese farmers especially value their oldest soils, which have been occupied perhaps for six thousand years and descended through the same family for hundreds of years, more than they do their virgin soils, for the older soils are better understood, are under more perfect control and are considered surer and more productive.

A farmer in this country interested in live stock should choose a different type of soil for the raising of young cattle, for the feeding of beef animals, or for the handling of dairy cattle. He should select different types of soil for the production of general farm crops and for the production of different kinds of early truck crops. In the production of general farm crops he should select different types of soil for the different types of tobacco, for rye, for buckwheat, for the hay grasses or for the pasture grasses. While he uses often the same type of soil for the production of wheat, corn and potatoes, he should come to realize that different types of soils are better adapted to each of these crops.

For the greatest success and the highest efficiency the farmer like the mechanic must not only know how to select the proper tool, that is, the proper soil, for a particular crop or system of farming, but he must understand his tool, that is the soil, as the mechanic does his tools or the factory man his factory, or the engineer his engine, to obtain certain and satisfactory results.

Three hundred years ago at the end of the baronial period in England, when the population was about as dense as that of the United States ten years ago, farms were abandoned through injudicious methods of agriculture and farmers moved from place to place as we are doing to-day. The yield of wheat was about 12 bushels per acre as against 16 bushels at present in this country. With increasing density of population, however, and the beginning of the more permanent land tenure and through force of necessity better methods were introduced, and the yield of wheat in England at the present time is about 32 bushels per acre.

Our knowledge of the soil is undeniably increasing, our farmers are gradually acquiring that intimate knowledge of the soils, their complexities and their needs, which is essential to success; so that in spite of the many individual failures to obtain average yields in this country and to increase the average through elimination of failures, and in spite of the shifting farm population the yields of wheat and of corn are steadily but slowly increasing owing to the improved methods that are gradually superseding the older and less efficient methods. The progress is slow; we are far from the ideal as is evidenced by the fact that the California Experiment Station [1] recognizing the importance of the man in his partnership with the soil states that the average yield of wheat in that State is 16 bushels per acre; a good yield which competent men may hope to obtain is 25 bushels; a yield not infrequently obtained under favorable conditions is 40 bushels; a possible but extraordinary yield is 50 bushels.

Experience for the man who enters a partnership with the soil to produce certain crops counts for a great deal, but this is by no means all that counts for success. A man may practice on a piano for years and yet his experience may not make him a successful musician. In law, in medicine, in surgery, or in mechanical trades with the same books and with the same tools experience alone does not account for the difference in the success attained. There must be a capacity in the man himself to fully benefit from the experience, — a capacity for close observation, for technique and for a sympathetic understanding of the subject and of the tools with which he works. This is recognized as ability, instinct, intuition, and may come in part through inheritance. A mother can not explain how she rears her first child nor can we explain whether it is through instinct, intuition, or inheritance that this mother's love and sympathetic understanding of the nature and needs of the child come from. It is not experience, for she has had no former experience, although she acquires experience as the child develops. A hen gives the same intuitive treatment to her first brood of chickens.

The housewife can not tell you how she raises house plants nor can she tell other women how to be equally successful. It is her sympathetic understanding and intuition as to the treatment they require.

The successful farmer must have this same sympathetic feeling and interest in his partnership with the soil. By association with other workers he learns the simple operations of the farm; through observation, experience, and to a certain extent through inheritance he acquires a certain technique and given capacity

[1] Circular No. 210, 1919, p. 3.

comes to have a sympathetic intuition as to the character and needs of his particular soil type. Through education, training and special investigations he may learn the reasons for doing things which will prepare him for doing things better and more intelligently, but the responsibility for the care and efficient conduct of the soil is on the man. The responsibility for failure can not be placed upon the soil, for history gives many illustrations of the fact that in one way or another the soil has continued to support the people through many generations. The responsibility is not to be placed upon natural causes, for the man must coöperate with nature, or if necessary oppose nature in his care of the soil, as the mother opposes and fights natural causes when the child is sick. The man may seek advice from his neighbors or from soil scientists but the responsibility does not rest on them except for helpful advice and information that may strengthen and fortify or influence the man's judgment and his methods. It is far easier and more agreeable to attribute failure to nature and to the soil than it is to recognize and assume the personal responsibility and to admit the failure to be due to human inefficiency, but this is usually not a fair way to place the blame.

In the modern concept of the soil the man has a leading part. He is the intelligent and constructive principal of the partnership in the production of crops and we can not fail to see from the illustrations given that so far as crop production is concerned the man must be reckoned as a part of the soil and very properly he comes first in the consideration at least of the productive capacity of the soil.

The Soil Scientist

In all ages the masses of the people have had a very comfortable feeling that while life is progressive and they know more than their fathers they know about all that is essential or obtainable about the affairs of life and of living. A few people in all ages have been dissatisfied with their present knowledge or practices and have attempted to reason from the known to the unknown to extend their knowledge with the hope of developing new facts and principles which will benefit mankind. Such men were known as philosophers, or more recently, as scientists. In the olden days such advanced thinkers were often persecuted, imprisoned and sometimes killed by the masses to prevent the spread of their doctrines, yet philosophy or science has persisted in spite of discouragements and lack of adequate support to overthrow ignorance and revolutionize ideas and methods making possible the present intricate state of society.

We have apparently authentic written evidence of the history of mankind extending over a period of some 6,000 years, but from evidence furnished by geology it seems apparent that man has occupied the earth for hundreds of thousands of years. These older people have left no written evidence of the period of their existence; the only evidence we have of the age of the fragments of bones and of skeletons we find in clays and rocks is with respect to the estimated time it has taken for the geological changes to have occurred since these clays or the materials of the rocks were originally laid down on what was then the surface of the earth upon which the human being walked.

When one looks back at the time of Washington or at the time of the signing of the Declaration of Independence, less than 150 years ago, one is impressed with the slight advances which had been made in the material sciences. Transportation and communication on the land was dependent entirely upon the horse or the ox and on the water to small sailing vessels. The cities of Wilmington, Baltimore, Georgetown, Richmond, Charleston and Augusta were located on the fall line of the rivers whose waters dashed over the rocks of the Piedmont into the softer material of the Coastal Plain giving water power on the one hand for manufacturing and quietly flowing rivers and estuaries for the transportation of manufactured articles on the other. They had neither steam nor electric power, the coal deposits were still hidden mysteries of nature and the knowledge of ores and of metals was not much advanced over that of the ancients.

Up to that time the barbers were called upon to do most of the surgical operations. It is true that in England in 1540 Parliament passed an act providing "That no person using any shaving or barbery in London shall occupy any surgery, letting of blood or other matter, except only drawing of teeth;" but it was not until 1745 that the surgeons and barbers of London were separated by law into two distinct and separate corporations. It was not until after our own Civil War, from the researches of Pasteur, Lister, and others and by the use of anesthetics that surgical operations could be performed with any assurance of recovery and that the delicate operations that are now performed were made possible. Instead of the drawing of teeth being entrusted to barbers, as was done in the act of 1540, we now have specialists in dentistry that operate solely on this or that division into which the subject has been divided.

The history of the use of iron is one of the most spectacular achievements of modern scientific thought with inert material. The ancients were familiar with iron ore and had methods of extracting iron from it. Later they became acquainted with the three forms — cast iron, wrought iron and steel. Marvelous tales are told of the Damascus blade, the methods of producing which are supposed to have been lost in the middle ages. Iron is one of the commonest metals we have; it appears commonplace in the extreme. The ancients no doubt considered that the last word had been said after the Damascus blade had been developed out of iron ore.

The recognition of the differences in the magnetic and electrical properties of iron and steel have made possible the telephone and the telegraph as well as the wireless transmission of thought through space. It has been found and only recently been found that the properties of steel are greatly changed by the amount of silica, carbon, manganese, tungsten, titanium, vanadium and other substances, which frequently need to be present only in fractions of a per cent. This knowledge and its application has made safer and more rapid transit on the railroad, the building of the great modern buildings and bridges and a multitude of other conveniences upon which modern civilization, industries and commerce are dependent. The automobile probably has assembled in its body, engine and transmission the greatest variety of kinds of steel and iron, that is assembled in any one object of the present day. By the use of steel of different properties in its several parts, it is approaching the mythical one-horse shay in which every part was of equal strength and which dissolved in pieces all at once and nothing first. With all the recent advances in our knowledge and practical use of iron and steel no scientist would think to-day that the last word has been said, that all the mysteries, powers and weaknesses have been developed. They even believe now that steel in constant use becomes fatigued. What a marvelous thought that a substance apparently so inert and apparently unorganized should suffer from fatigue as does an ordinary animal!

Our farmers to-day have become familiar with the terms nitrogen, ammonia, potash and phosphoric acid, as they have been taught that these substances in the soil constitute a valuable part of the food of plants and they have come to apply different compounds of these materials to their soils in commercial fertilizers. Nitrogen was unknown, however, until the year 1772, and while ammonia compounds had been known by the ancients ammonia gas was not discovered until 1774. While glowing phosphorus was known to the old alchemists and was used in some of their mysterious rites it was so difficult to prepare that as late as 1730 the price was extremely high and it sold in London for from 10 to 16 shillings per ounce. The occurrence of calcium phosphate in bones was not known until 1769, and it was first obtained from bone ash in 1771. Potassium was not discovered until 1808. So we see that it has only been within a comparatively few years as compared with the ages of mankind's history that knowledge of facts has been accumulating which has made it possible to understand the mysteries of the soil and to plan intelligently for overcoming the menace and the threat which the soil presents to one who wants to go beyond the narrow line of production where nature uncontrolled has set a limit. Beyond this natural limit of production one has to fight or to control nature to win success.

It was not until Liebig's classical work was announced in 1840 that any very serious consideration was given to the study of the soil in its relation to crop production other than the empirical knowledge gained by practice which was known to the early Roman writers. Liebig pointed out that certain newly discovered materials such as nitrogen, phosphoric acid, potash, lime and other substances were essential to the growth of plants. Two things resulted from his investigations. One was the systematic preparation of commercial fertilizers which have proved such a boon in the hands of the intelligent farmer as a means of increasing his crop yields; the other was an idea that the relation of the soil to crop production could be discovered by a comparison of the chemical analysis of the soil made to determine the relative amount of available mineral plant food with the analysis of the plant which it was proposed to raise upon the soil. This idea was not so successful as the other, and after seventy years of diligent research no such simple relation has been established.

The soil scientist of to-day believes the soil to be a living organized thing with properties and functions which react on each other as is common with organized beings. Man in his partnership relations with the soil in the production of crops has to fight nature at every step to win the increase in production over the limit that nature sets. He has neither the time nor the equipment to study the natural forces to which he is opposed. He does not see the menace or the threat which nature interposes against the realization of the promise nor can he study the weaknesses through which alone these natural forces may be overcome and made subservient to his needs. The soil scientist has therefore entered the arena and has undertaken to grapple with the farmer's partner, the soil, to make a diagnosis of its troubles and to provide the farmer with means whereby he can overcome adverse natural forces and make the soil more obedient to his will and to his needs. The soil scientist has the same relation to the partnership between the man and the soil that the lawyer has to a corporation, — that the chemist has to the steel or dye manufacturer. The lawyer and the chemist do not run the corporation or the factory, but advise the administrative head so that he can act in a safer and more efficient manner. The soil scientist does not run the farm for he has not necessarily the experience, the training, or the intuition of the farmer, but he advises how the soil may be handled more efficiently. His training, knowledge, and experience come from observations in the field and in the laboratory. In the field he studies the essential differences between soils that constitute a soil type. He knows the texture, structure, profile, color, drainage, topography, origin and all observable physical characteristics as one would study the form, shape, size, color and other physical characteristics of breeds of cattle, horses or men. He observes the relation of the soil type to native vegetation, to crops and to methods of cultivation. In the laboratory he studies the chemical, physical, and biological differences between soil types and particularly the abnormalities resulting from natural causes or from cultural methods. He is constantly attempting to make a complete diagnosis of the soil to detect abnormalities, to search out weaknesses, and to prescribe methods of attack through which these weaknesses can be overcome.

The physician can offer no helpful advice in average health. The veterinarian can offer no such advice in regard to an animal in average health. The physician does not understand the reason why one man is a husky laborer, another a successful scientist, another a great painter or a musician. The veterinarian does not understand the reasons for the difference between a Jersey and a Holstein cow or between a draft horse and a race horse. We expect these differences and aim to utilize them to the best advantage. It is no more to be expected that the soil scientist should be able to tell the reason for the differences in soil types. It is important, however, that these differences be recognized in order that the soil type should be most efficiently used. It is no more desirable to have soils uniform in their relation to crops than it is to have a uniform breed of cattle or to have horses all of one type or men all of a single capacity to work. The important thing in life is to recognize differences and develop them for their most efficient use.

If a man is sick, whether he be a laborer, a clerk, a professional man or a musician, that is if abnormalities develop in his digestive, circulatory or nervous system, the physician is relied on to diagnose the trouble and to prescribe treatments that will restore normal functions. It is not necessary to have one class of physicians for clerks, another for professional men, and another for musicians. It is, however, necessary in our present stage of knowledge to have physicians who are experts on certain diseases and certain disorders. In the same way the term soil scientist is a general term under which come specialists in chemistry, in physics, in biology, and in classification.

Many people who look upon the soil as simple, inert matter, expect a chemist to advise from an analysis of their soil what crops it will grow and what treatment it requires. This is utterly impossible for it does not take into account the many functional activities that react on each other and it does not take into account the man who is the intelligent and directive agent in the partnership and what he has done in the past to bring about abnormalities in the functional activities of the soil.

It is entirely impossible and undesirable in a book of this scope to explain what a soil scientist at present can or cannot do, just as it would be impossible to explain what a physician does. The subject is so complex that books and monographs by the hundreds have been written on every phase of the soil's activities and as with medicine or with surgery a man must keep abreast of the time, watch every advance that has been made, and be prepared to use or to have others qualified in a particular field use the most advanced methods of research for diagnosing the trouble and for prescribing remedial methods.

Tragedies of the Soil

In all life the things that impress themselves upon the human mind are the tragedies — the quick and sudden changes from life to death — rather than the slower changes involved in natural processes. The impressive things in the history of the world are the wars and revolutions leading to the overturning of nations or the overthrow of political parties rather than the gradual evolution of our civilization continuing through the centuries. And to a lesser extent interest centers in the more startling inventions or philosophies that, working through mental revolts and intellectual wars, have made it possible to overcome and to overthrow ignorance and superstition and to bring about control and development of a more progressive state of society.

In the manifestation of natural forces, which have impressed themselves upon the mind of man, we have, on the sea, the storm and tempest, the iceberg, and the hidden rocks that have caused tragedies in the loss of life and property which the skill of the navigator has been powerless to prevent. Such tragedies have been recorded in literature, in history, poetry and fiction and have had no small part in the general education of mankind. On the land, tornadoes and floods, earthquakes and volcanoes, landslides and conflagrations have caused tragedies in the loss of life and property which have similarly been recorded in literature. The great conflagrations in Chicago, Boston, and Baltimore, the landslides which take their toll almost every year in the Alps, the volcanic eruptions so strikingly pictured in "The Last Days of Pompeii," the earthquake at San Francisco, the floods of the Ohio and Mississippi Rivers, and the tornadoes which seemingly are not confined to any locality are facts which fix themselves in the minds of people.

The scourge of disease which in times past has decimated towns, cities, provinces and even continents, such as the black plague, the bubonic plague, cholera, yellow fever, smallpox, typhus and typhoid fever and influenza have similarly been recorded in literature as facts that appeal strongly to the imagination of people.

The knowledge of facts alone, however, does not constitute a very high order of education. It is the study and analysis of the facts and the underlying causes and methods of control for the welfare of mankind that develops the higher order of education. It is the meeting of these great forces of nature by human intellect and their mastery and control so life and property can be conserved that stands for the greater education.

The great tragedies to which reference has been made which are highly spectacular and impress themselves upon the minds of the people are really small and insignificant compared with the aggregate of the loss of life and property through neglect, indifference, and ignorance of what appear to be the commonplace things in business, in the home, on the farm, in the livestock and in the soil type. The loss of efficiency, the fruitless efforts, the entanglements, the loss of hope and the loss of life and property constitute the real tragedies of life, but being unorganized and applying to the individual are not spectacular and are not recorded in literature. So we let tuberculosis, cancer, the social diseases and other minor diseases take their toll to an extent that would startle the world if they were constricted to small localities in organized social communities instead of being scattered as they are in individual cases throughout the world. Many of these we know can be prevented by proper precautions and by proper watchfulness and consideration by the individual and by the community through such commonplace things as diet, exercise, care of the mind and body, proper occupation and clean and healthy surroundings.

A few devoted men and women in all localities see the need of improvement and uplift in the life of the individual, in the care of property, in business methods, in safety of travel, but their efforts are generally unorganized or the problems so complex that progress is slow. Our schools and colleges, churches and societies, community centers and business organizations are all working for the uplift of society, but for the most part the problems seem so commonplace to the individual or so involved that his interest is not aroused and things are permitted to go on much as they have formerly proceeded. It is only an occasional individual who attempts to learn the strength of the enemy, to study his resources and his weaknesses, who lays plans through his inventions and discoveries or through strong logical deductions, that succeeds most strikingly in obtaining a mastery over the common enemies of mankind.

In the care of livestock and in the use of a soil type there are enemies to overcome and to overthrow if success is to be attained. Each individual animal or soil type must be studied, its resources and possibilities, its menace and weaknesses must be understood to gain ultimate success. In spite of the teachings of the agricultural colleges and experiment stations, of the Department of Agriculture, of the county agents, and of the farm organizations there is an inertia among the people that is difficult to overcome. We urge them to study and try to understand the nature of this or that type of soil, upon which they have located and upon which their life is being spent to win success in agriculture in the production of food and clothing for themselves and for society. They see the promise but they do not realize the threat and the challenge of the common enemy of mankind that must be met and overcome before the promise becomes a reality. The dangers encountered against successful agriculture on the farm appear remote, without substance, and without definite menace. It is in regions beyond the settled communities, in the advanced places of civilization and of the pioneer that nature sometimes speaks in such awful tones that the mind is compelled to recognize the dangers and to take organized and conscious effort to overcome them for the preservation of life. A few illustrations will be given.

The Goodwin Sands off the English coast in the days of the old sailing vessels were known as one of the graveyards of ships and of those who traveled on them. They still remain a menace to commerce and navigation. They represent an irresistible force that brings death and destruction to vessels that are once caught by them. The disasters and the tragedies associated with these sands have become a part of history, of poetry, and of fiction.

The Goodwin Sands constitute a great sand bank some 8 miles long and about 4 miles wide rising through deep water. Their nearest approach to the town of Deal on the English mainland is about 4 miles, which space constitutes a deep channel and anchorage called the Downs. Through this channel pass the inward and outward bound commerce from London and the north of England, from Holland, Germany and the Baltic, from the Americas, from Africa, from southern Europe, India, Australia, China and Japan. At high tide these sands are completely covered with water to a depth of some 6 feet; at low tide they project some 6 feet above the water's surface. When exposed above the water they are hard and firm and one may walk for miles as on a hard beach sand. As the tide rises they get soft and the foot sinks in an alarming manner. At low tide they are desolate in the extreme and the mind of man is appalled by the thought that below him are layer upon layer of ships and all they contain both of property and of lives that have been wrecked and swallowed by this insatiable monster of the deep. In 1703 it is reported that 13 men-of-war were wrecked and disappeared into the capacious maw of this monster. What a world of tragedy is written in this stretch of sand the properties of which are not understood and have not been conquered in the ages that have passed since England's maritime trade has been developing.

The materials of the Goodwin Sands are not unlike the materials of the Norfolk sand and sandy loam of our own Atlantic seaboard and if it were humanly possible to reclaim them they could be occupied by farmers and their families in peaceful homes growing ordinary farm crops or where advantageously located in producing the great vegetable crops that feed our cities in the winter and early spring before the local crops mature. The Goodwin Sands are feared and avoided if possible by all people who travel by sea because of the tragedies that have occurred to life and property through the awful forces operating in them. The Norfolk types of soil in our own country appear peaceful, harmless, and serene, yet it is safe to say that these Norfolk soils have caused more tragedies in the loss of life and property through ignorance of their strength, resources, and weaknesses, through loss of energy, loss of money, loss of hope and loss of life than have the Goodwin Sands of the English coast. The newcomer sees their promise as demonstrated by the master men who have attained success, but they fail to understand the challenge or the menace, they do not even think of the mysteries, they have not gauged the weaknesses upon which to plan an intelligent campaign which will win for them the path to ultimate success. The doom of the ship which strikes the Goodwin Sands is quick and awful in its destruction of life and property. The doom of a man who is shipwrecked on a soil type and does not win his path to success is slow and enduring and commonplace so that his final end is not spectacular, is not recorded in literature, and does not stand out as a buoy to warn other men to avoid the tracks or paths that he has followed.

We read with awe the powerful description of Victor Hugo of the awful tragedies that have occurred in quicksand. Who has not shuddered at his portrayal of the irresistible force of this enemy of mankind against which it is hopeless for the individual unaided to combat when once he is brought under its power? "Les Miserables" has made of quicksand a living, powerful, organized force against which the puny efforts of the individual are impotent. The following is the description:

"It sometimes happens, on certain coasts of Brittany or Scotland, that a man, traveler or fisherman, walking on the beach at low tide far from the bank, suddenly notices that for several minutes he has been walking with some difficulty. The strand beneath his feet is like pitch; his soles stick to it; it is sand no longer, it is glue. The beach is perfectly dry, but at every step he takes, as soon as he lifts his foot, the print which it leaves fills with water. The eye, however, has noticed no change; the immense strand is smooth and tranquil, all the sand has the same appearance, nothing distinguishes the surface which is solid from the surface which is no longer so; the joyous little crowd of sand fleas continues to leap tumultuously over the wayfarer's feet. The man pursues his way, goes forward, inclines toward the land, endeavors to get nearer the upland. He is not anxious. Anxious about what? Only he feels somehow as if the weight of his feet increased with every step which he takes. Suddenly he sinks in; he sinks in two or three inches. Decidedly he is not on the right road; he stops to take his bearings. All at once he looks at his feet; his feet have disappeared; the sand covers them. He draws his feet out of the sand; he will retrace his steps; he turns back, he sinks deeper in; the sand comes up to his ankle; he pulls himself out and throws himself to the left, the sand is half leg deep; he throws himself to the right, the sand comes up to his shins. Then he recognizes with unspeakable terror that he is caught in the quicksand and that he has beneath him the fearful medium in which man can no more walk than the fish can swim. He throws off his load if he has one, he lightens himself like a ship in distress; it is already too late, the sand is above his knees; he calls; he waves his hat or his handkerchief; the sand gains on him more and more. If the beach is deserted; if the land is too far off; if the sand is of too ill-repute; if there is no hero in sight, it is all over — he is condemned to *enlizement;* he is condemned to that appalling interment — long, infallible, implacable; impossible to slacken or to hasten; which endures for hours; which will not end; which seizes you erect, free, and in full health; which draws you by the feet; which, at every effort that you attempt, at every shout that you utter drags you a little deeper; which appears to punish you for your resistance by a redoubling of its grasp; which sinks the man slowly into earth while it leaves him all the time to look at the horizon, the trees, the green fields, the smoke of the villages in the plains, the sails of the ships upon the sea, the birds flying and singing, the sunshine, the sky. *Enlizement* is the grave become a tide and rising from the depths of the earth toward a living man. Each minute is an inexorable enshroudress. The victim attempts to sit down, to lie down, to creep. Every movement he makes inters him. He straightens up; he sinks in. He feels that he is being swallowed up; he howls, implores, cries to the clouds, wrings his hands, despairs. Behold his waist — deep in the sand. The sand reaches his breast, he is now only a bust. He raises his arms, utters furious groans, clutches the beach with his nails, would hold by that straw, leans upon his elbows to pull himself out of this soft sheath, sobs frenziedly. The sand rises; the sand reaches his shoulders; the sand reaches his neck. The face alone is visible now. The mouth cries; the sand fills in — silence. The eyes still gaze; the sand shuts them — night. Then the forehead decreases, a little hair flutters above the sand, a hand protrudes — comes through the surface of the beach — moves and shakes and disappears. Sinister effacement of a man."

Through organized and intelligent effort these quicksands may be subdued and reclaimed. A home may be established and food produced by a master man but however firm and safe the surface may become a man who does not understand the mysteries, the weaknesses, and the methods of control may sink deeper and deeper into debt until he is submerged in a business sense as completely as in a physical sense before the quicksand had been altered. Such tragedies are constantly occurring on the farms of this and of other types of soil when occupied by those who do not know or are not able to comprehend enough of the mysteries, the capacities and the weaknesses to win success.

Sand dunes are common along the shores of lakes and oceans but are much more common and more dangerous in hot and arid countries beyond the range of civilization. On a hot quiet day the traveler may be charmed by the fantastic shapes and the peculiar colors of the dunes along which he is traveling, but suddenly the air becomes charged with a mist, a feeling of uneasiness and of oppression is felt by man and animal, a mysterious electrical atmosphere seems to prevail, the wind rises and the sand begins to cut the face and hands, the experienced traveler pauses and unhitches his animals, erects a barrier on the windward side, the air is filled with yellow dust through which the sun shines feebly and is finally obscured from sight. The storm may last for two or three days of suffocating, terrifying moments. Suddenly the wind abates, the atmosphere clears and the survivors, if any are left to tell the tale, look upon a new world in which all former paths have been destroyed and the face of nature has been changed. They dig themselves and their outfit out and proceed slowly and with much labor to a haven of refuge.

Conditions like these have been met and have been overcome by master minds; sometimes through the planting of trees or of herbage where conditions are favorable for plant growth; other times through the development of plans made by engineers who have finally subdued the enemy through the installation of an irrigation system. Through the efforts of the engineers the land has been finally turned into a fertile country in which the settlers and their families have to work out their own salvation. In such cases of reclamation are many failures of men who are not master-men who could win success but with survivals sufficient to ultimately make the enterprise successful.

Who has not been thrilled with the awful tragedies that have occurred on the deserts to travelers who did not understand their mysteries and their menace and who had not learned that only in certain directions and by certain routes could they be crossed with safety? On these vast desolate stretches, where miles mean nothing, where there is no sign of human life except perhaps a faint and poorly defined path, there is a fascination and a promise that leads one on in spite of the silent menace, the quiet waiting, the threat and the challenge. The sun beats down mercilessly using all its powers to keep intruders out; the silent nights with the myriad of stars so far away and so brightly burning through the dry atmosphere; the peculiar sounds that make the stillness seem a living stillness and awe inspiring; the pungent odors that seem to intoxicate the brain with a peculiar fascination; always the fierce bright light of day from unclouded skies with the dream visions of lakes of water tantalizing the thirsty traveler; the dreamlike visions of tinted hills which fade away as one approaches the stern realities of the continuously dry and arid country; the sand dunes that baffle the judgment as to direction and at times shift through mighty forces of the dust storm which stops all progress during its continuance and threatens to engulf the traveler. At other times there is the silent waiting — waiting — waiting; always a peculiar fascinating promise but with the promise a mystic call, always with the threat and danger.

In a less awful way with apparently much more promise the contemplation of the soil type has its mysteries and menace, has its natural forces to combat, through an appreciation and knowledge of their weaknesses as points of contact to overcome as in the desert. It is the master man, the man with experience, with intuition, natural acquirements or knowledge who wins out in his mastery of the soil as in the desert.

The Bad Lands of the Dakotas, or as one writer calls them "The Bad Lands to Pass Through," have been made famous through the history of the Indian wars and through the tragedies that have occurred in western emigration where the troops and trains have lost their bearing through lack of intelligent guides. The scout or guide may be woefully ignorant of literature and art but possessing an intuitive knowledge of the intricacies of the eroded lands can pass through in safety.

Alkali has been a menace to progress in certain parts of the world, the deposits being often hidden beneath the surface and covered by every prospect of fertile conditions. Great irrigation systems have been developed with apparent success when this hidden menace has arisen to devastate entire districts. Fortunately by modern methods of observation its presence can now be revealed and its subjugation is possible by proper treatment of the land.

Soils with adobe properties found in the arid regions of the West and generally in arid countries are well known in history and literature as they have been used for the construction of houses, of temples, and of villages by modern and by prehistoric peoples. Who has not been thrilled by the tales of adventure of

Cortez, the Pizarros, Orellana, Valdivia and Balboa of the villages and temples of races of people then long extinct whose records, character and manner of living are still being studied through the remains of these adobe buildings. The use of adobe soils in prehistoric buildings is of great interest in exciting the imagination of mankind, but the use of adobe soils for agriculture being a commonplace event excites little interest and no mention in the literature in spite of the many failures and tragedies that occur on the farms because men do not understand them or appreciate their resources, their properties, and their weaknesses as agents in the production of food and clothing.

Mankind is beginning to understand, appreciate and utilize different breeds of cattle and different kinds of domestic animals. He is beginning to understand the different treatments they require for their highest efficiency in the production of labor, food and clothing. He is beginning to realize more fully and more completely the promise through the control of natural enemies within and without the body and in controlling the functional activities of the animal to meet the requirements of himself and of mankind.

The soil types all have their points of difference, they have different capacities, different weaknesses, they respond to different kinds of treatment, are adapted to different associations of crops, and they all have their promise, but their menace and their secrets make them as difficult to pass through as the Bad Lands of the Dakotas or the desert. But the tragedies that occur due to ignorance or inability to combat the hidden enemies are not spectacular, are not recorded in history or other literature and are quietly passed along as the commonplaces of life or as failures due to natural causes against which the individual feels that he has been powerless to contend.

Numerous tragedies have resulted in an indiscriminate settlement of the lands of the United States. There are some types of soils which were not then understood, nor even yet are understood. We do not know of anything that they are particularly adapted to.

Three or four hundred years ago a colony was established on the Hagerstown loam soil around what is now known as Lancaster, Pennsylvania. The success of these people on this particular soil type has been the admiration of the country. It has been an object lesson to American farmers; it has influenced American life and patriotism. The people have been contented for they have been able to produce a large part of what they need and a considerable surplus to distribute to others. They have comfortable homes, plenty to eat, large and commodious barns and have seen the value of their lands increase as time passed. They have been able to clothe and educate themselves and their children.

About the same time a section of the sandhills and mountains of some of our Southern States was settled by much the same kind of people, but their history has been in terrible contrast with the history of the Pennsylvania settlers. No human effort then or now would get their soils to produce an adequate supply of material for their needs. The people have been undernourished and diseased. They have been poorly educated and have been utterly discouraged and are without ambition. Instead of being an example and an inspiration to the people of other localities, instead of contributing to the general welfare of the State and Nation they have been a burden and a care and a menace. Well would it have been for the country as a whole and for these individuals in particular if they could have been prevented from settling on these soil types until crops could have been found and introduced with which they could have competed on fairly equal terms with settlers on more productive soils. These are pertinent illustrations of the part that the soil type has played in the development of people, of character, and of health in the growth of our national domain.

The Soil as a Living Thing

Reference has been made in previous pages and will be made in subsequent pages to the Soil as a Living Thing. In its properties and functional activities the soil resembles more a living animal than a living plant. The lower forms of animal life resemble the lower forms of plant life so they can hardly be distinguished one from another. The lower forms of animal life have not the power of locomotion, the obvious organized structure, and so far as we know have not the nervous system nor the brain of the higher order of animals. The soil has in itself no power of locomotion, no nervous system and no brain; in other respects it resembles the more highly organized animal.

The analogies that will be brought out with the animal are to emphasize the highly organized and complicated system in the soil which distinguishes the modern concept of the soil from the old idea that the soil is static and rather inert. The soil is not an animal but the interrelation of its properties and functional activities, the resultant of which forces measures its productive capacity or efficiency, can at this stage of our knowledge be most strikingly brought out through the analogy with the living animal, a subject with which we are all more or less familiar. Analogies are helpful in conveying ideas and impressions but they are harmful if they are taken too literally and as meaning the same thing.

Both the animal and the soil have the following in common as distinctive features of the body:

Color
Skeleton
Tendons and muscles
Colloidal linings
Digestive system
Respiratory system
Circulatory system

Color. — The color of animals is indicative of certain differences in functional activities. What relation the color has to functional activities has never been explained. In so far as it is inherited it marks, a difference between races of man or breeds of cattle or kind of animal and is rather a race distinction than an individual characteristic. However, the shade of color is often indicative of individual functional peculiarities and is often relied upon as an indication of health or disease or even of constitutional disorders.

Familiar examples of the relation of color in animals as indicative of their functional differences is seen in the Jersey and Holstein cows, in the Percheron draft horse as compared with the thoroughbred race horse, in the white and black bears, in the characteristic banding of the zebra, in the White Wyandotte, Plymouth Rock and the Rhode Island Red among chickens, and any number of brilliant differences in the color of birds.

The color of the soil material is quite as indicative of soil character as it is of animal characters. A red color is indicative of different functional activities in the soil from a black, yellow, brown, white or purple color. A gray soil overlying a red subsoil or a black soil overlying a white subsoil indicate differences in functional activities within the soil as a whole. One can often tell from the color of the material the class of crops that can be most efficiently produced or the treatment necessary to increase the efficiency of the soil for the general class of crops to which it is adapted. Even the shade of color or tint appears to be associated with functional activities which limit productivity and adaptation to crops and to the kind of treatment that is required to make a soil more efficient. In many cases, however, we do not as yet understand the cause or the effect of conditions indicated by these color changes, how they can be overcome or accentuated as may be desirable to secure the most effective use of the soil in agriculture. In other words, a sign is given for guidance which we as yet can not read or interpret. The color of the soil material is therefore an important element in the classification of soils, even if we do not at present understand and appreciate the exact significance and practical importance of the subject.

Skeleton. — The higher animals have a skeleton [2] to support

[2] The skeleton of the soil is determined and studied through the methods of mechanical analysis all of which depend upon a thorough agitation of

the various membranes and organs that take part in the functional activities. This framework varies in size and arrangement of its different parts to accommodate the organs and to meet the requirements of the activities of the animal as a whole. In some animals the skeleton is extremely small and fragile marking a limitation of the load that can be put on the animal or the kind of work which the animal can be expected to perform. Others have a more massive frame permitting of greater speed

---

the soil with an excess of water and separating out the mineral particles by subsidence in water of the very fine material and the separation of the coarser material through sieves of different sized openings. The grades of material thus separated are conventionally determined and differ in different countries. In the Bureau of Soils material that passes through a sieve with round holes 2 mm. in diameter and does not pass a sieve with 1 mm. holes is conventionally called fine gravel, material from 1 to .5 mm. coarse sand, from .5 to .25 medium sand, from .25 to .1 fine sand, from .1 to .05 very fine sand, from .05 to .005 silt and from .005 down is called clay. The proportion of each of these grades of material is taken to represent the skeleton of the soil. If the soil were composed entirely of the first grade, that is, of fine gravel the skeleton would be so coarse and open that it would not have the power of maintaining an adequate circulatory system under natural conditions. It would be very unlikely to have more than a trace of colloids nor to have material in it for an adequate digestive system. If on the other hand the soil consisted entirely of material of the clay group the skeleton would be so fine grained and would have such a large colloidal content that it would not be workable under ordinary field conditions nor would it have that facility in the circulatory system necessary for the support of cultivated crops. Most of our agricultural soils are made up of mixtures of these different grades and the skeleton is said to vary with the proportion of the grades of material found to be present. We may, therefore, have a coarse sandy clay on a fine sandy loam, which expresses a skeleton formation which is more or less familiar to all farmers. There may be no essential difference in the grade designated as silt from those designated as sands except the size of the particles. There is, however, a very material difference in the character of the clay from either silt or sand as this material has materially changed in form to a colloidal state of matter which has entirely different properties from those possessed by silt or sand. We have reason to believe that the arrangement of the different classes of materials in the soil may not have a uniform arrangement so that silt loam soils for example having identical proportions of silt and colloidal clay do not necessarily have the same physical character, the same respiratory, circulatory or digestive systems, and therefore may have very different physical properties towards cultivation and towards the production of useful crops.

or greater endurance under loads. There is an infinite variety in the structure of skeletons to meet the requirements of the activities of the animal and the work it is called upon to endure in its particular place in nature.

The soil has a corresponding skeleton of small rock fragments between the supporting walls of which the functional activities perform. This skeleton of the soil differs as does the skeleton of animals in a great variety of forms adapted to the different functional activities that nature has provided for the wonderful variety of natural plant associations and for human needs. Some soils are composed largely of coarse gravel or bowlders, others have a large proportion of coarse or of medium sand while others are composed largely of fine-grained silts and clays. These soils of different texture differ in their functional activities and relation to crop adaptation and production. There may be one texture in the soil, another in the subsoil and still another in the substratum. There may be beds of gravel or of hardpan below the surface, which affect the functional activities of the soil and what it can do in the way of raising crops and the way it must be treated to insure satisfactory results. A coarse-grained, loose, incoherent sand is no more adapted to, and no more efficient in producing a crop of wheat than is a dog adapted to perform the work of a horse on the farm. Both the dog and the horse may be essential in their way on the farm but they are not useful in the same way nor are they interchangeable. So the coarse-sandy soil may be made of use but the purposes for which it can be efficiently used are as different from those of the well-drained clay soil as the purpose for which the dog is used on the farm differs from the purpose for which the horse or cow is used. The texture of the soil material therefore has an important place in the classification of soils for human needs.

Tendons and muscles. — The animal has certain tendons and muscles to hold the bones in place and take part in the functional activity of the body. The soil colloids act in a similar manner to hold the fragments of rocks together and give plasticity in the wet soil and compactness or hardness in the dry soil. Methods have only recently been devised for separating this colloidal material from the skeleton of the soil which permits a study to be made of the composition, constitution, and physical properties of the material. It is evident that this investigation will lead to methods of practical control of excessive plasticity or hardness which affects cultivation and often to the efficiency of the soil with respect to the production of certain crops. This is a matter of the utmost importance also in the construction and maintenance of roads. If economical methods can be devised for increasing the plasticity of loose and incoherent sands and of decreasing the plasticity of certain clays the subgrade can be adjusted in strength to properly support the road surface.

Colloidal lining. — The stomach and other organs of the animal have a colloidal lining to absorb and regulate the supply of nutrient materials in various parts of the body. The soil colloids act in the same way in absorbing and regulating the food supply in the soil. Were it not for these colloids in the soil which have the power of withdrawing from active solution mineral and organic substances as well as gases, all soluble material would be readily washed out of the soil by rainfall instead of being held in proportion to the needs of crops as is at present done. The soil colloids themselves are soluble in water in what is known as a colloidal solution, but these colloidal solutions and the potash and other salts they have absorbed are immiscible with water, that is they do not dissolve in free water, except to a very limited extent, and are therefore not washed out by rain. That portion of the water which is in the colloidal state with the soil colloid acts towards free water very much as oil does, and in dilute solutions forms little droplets that have the appearance of fat globules in milk. The nature and properties of these colloids with respect to their absorptive properties and the replacement of one substance by another is being investigated at the present time.

The Digestive System. — The animal has a complicated digestive system to prepare food that is eaten for assimilation by the body and for final elimination of unused food material and of waste matter from the body itself. The soil has a similar digestive system to prepare food for assimilation by plants and for the elimination of waste material in the soil and of waste material thrown into the soil by the plant itself. The soil is the home and the ultimate source of the bacteria, enzymes and oxidation processes that make for health or disease in the animal body. The food of the soil, that is the food that keeps alive the digestive agents in the soil, is first the crop and its waste products and secondly the organic remains of plants and animals. An animal has to be constantly fed with organic matter with the attendant mineral matter contained therein to maintain its digestive functions and an adequate food supply for growth and energy.

Animals differ of course as to the form in which the food is taken. Some animals require mainly seeds, others plants of different kinds, others live almost entirely upon the meat of other animals, all according to their digestive powers and peculiarities. Most animals require a certain variety of foods, different kinds or mixtures of seeds, and different kinds or mixtures of vegetable materials or of plants.

We have similar analogies in the soils. Soils differ greatly in their capacities to digest and to supply food in proportion to the needs of buckwheat, rye, wheat, oats, corn and other crops. Some soils seem to be able to withstand for a considerable number of years a single crop grown continuously. Other soils appear to be able to give satisfactory yields only occasionally, with other varieties of plants raised in the intervening years. Some soils appear to require one association of plants, while other soils appear to require or do better with a different association of plants whether growing simultaneously on the land or following each other in rotation. The reason for this is partly understood through the investigations of the Bureau of Soils and in investigations that have been carried on elsewhere. For instance, the Duke of Bedford on his English estate has shown that the injurious effects of weeds on fruit trees is due to material given out by the weeds which under the normal digestive system of the soil are toxic or deleterious to the trees. The same thing was indicated by experiments on weeds and corn at Cornell University. The same thing has been indicated by experiments in the Bureau of Soils showing the cause of the deleterious effects that certain trees have on vegetation surrounding the tree. In "Science" for October 14, 1921, is a list of some thirty-five organic substances which have been separated from the soil which have resulted from the digestion of protein, fats, and carbohydrates in different soils. These are similar to the digested compounds found in the animal body. Some of these organic substances have been found to be toxic to some plants and non-toxic or even beneficial to other plants. Some of the compounds have been found to be highly beneficial to plants. Some of the toxic compounds when mixed with nitrate of soda disappear or change their form, others when mixed with potash salts or with phosphate disappear or change their form. We have here probably one of the important reasons that fertilizers are beneficial in assisting the digestive powers of the soil in the elimination of toxic materials. This appears also to be a reason why fertilizers are more effective in some seasons than in others.

The waste material is eliminated from the animal by ejection through the bowels, the kidneys, the skin or the lungs and animals with the power of locomotion can move away from their waste products. The plant being fixed in its position has certain powers of protecting the absorptive powers of the roots by corking them over leaving only the extending tip to absorb in constantly new portions of soil. Having no power of locomotion it can not, however, remove itself from the excreta of neighboring plants nor from deleterious substances left by former plants nor from plant remains.

The function of the digestive system of the soil seems to be to digest the organic débris, breaking it down through certain steps or lines of changes finally forming humus which approaches the hydrocarbon stage, with most of the oxygen eliminated from the organic matter, with the result that the humus forms the natural sewage disposal of material, a form that is harmless to the plant and generally beneficial to the physical condition of the soil.

Where these digestive changes proceed in abnormal lines the soil shows the same condition of fatigue as regards plant production as the animal in case of overexertion and the consequent accumulation of products of a kind which can not be digested or eliminated fast enough for the animal's needs. Truly this is a complicated process of digestion in the soil as it is in the animal and will require long and intelligent study for comprehension and for practical control through cultivation, cropping and the intelligent use of fertilizers.

Respiratory System. — The animal has a respiratory system to assist digestion and the elimination of waste products. This takes place mainly through the lungs but also through the skin and consists in taking in a fresh supply of oxygen or air to assist in the oxidation process of the body and the elimination of the unused portion of the air together with gaseous products formed through oxidation from the body.

The soil has a similar system which is called aeration. The soil breathes deeply and frequently to depths of fifty feet and probably to much greater depths. This interchange of fresh air with the soil likewise brings about oxidation and assists in digestion and accomplishes the direct elimination of the gaseous products of digestion from the soil. We know that drainage conditions have much to do with the extent of this aeration and we commonly use the method of cultivation to assist the digestive processes in the soil.

Circulatory System. — The animal has a circulatory system in the blood to distribute the nutrient material and waste products to different parts of the body where they can be used by the growing parts or eliminated from the system.

The soil has a similar circulatory system in the movement of soil moisture which distributes nutrient material and waste products. It has the larger channels through which water passes rather quickly as in the veins of the animal and it has the capillaries where the movement is slower but more effective in many details. While we have been used to studying capillary action in tubes of a few feet in length and while lysimeter measurements have been made of a few inches or a foot or two of soil it will be shown in the last chapter that there are evidences that this circulatory system of a soil is very much more extensive than we have heretofore conceived and that these capillaries act for many miles in depth and in lateral extent, so that the soil we cultivate represents but a thin skin on the earth which contributes as a whole to the circulatory system and all that this means in the distribution of nutrient material to the soil layer.

Conclusions. — We can not fail to see in this broad and comprehensive view that the soil is truly a living thing, that it has very complicated functional activities that react on one another and affect its productive power in the growth of plants. It is certainly not inert material. It will be seen also that a man having a sympathetic, an intuitive, or an inherited ability to handle the soil as he would have to handle a particular breed of cow, has a great advantage in the struggle for existence and in competition with a man who is lacking in knowledge and experience of the particular type of soil upon which he happens to be located. It also shows very clearly the complexities of the problem presented to the soil scientist in understanding the soil and its properties as related to the production of crops. It also indicates very clearly that the last word in crop production can not even be speculated on until we have a clearer knowledge of the soil as a living thing.

The question of plowing and cultivation, what they do and how they should be applied to different soil types needs to be worked out; the question of crop rotations, how they affect the soil and how they should be efficiently used; the question of manures and fertilizers how they affect the soil and how they should be prepared and applied, offer a large field of research. They are none of them simple things as we have heretofore thought but methods of controlling the functional activities of a very complex machine which is used for the production of food and clothing by mankind.

The Soil Type

In the present complex state of society certain men have to think and plan for the general welfare of society, and to give them the time and opportunity to think to some purpose, they have to be fed, clothed and housed by food, clothing and houses raised and prepared for them by others. Certain other men who formerly had time to devote to raising their own food and largely to clothe and house themselves now have to work in the mines, in the factories, in the stores and counting houses, in all lines of transportation, commerce, education, training and the treatment of injuries and disease. This vast increase in the proportion of men who no longer have time or opportunity to raise their own food or clothing material together with the great increase in the total population of the world is increasing the responsibility of the man and of the soil and is calling for more and more intensive work from both the man and soil, so that larger crops per acre and per man may be raised to supply the ever increasing needs of the world.

A block of marble contains an infinite number of potential forms that are unseen by the masses of the people. A master artist or a sculptor by following lines that he alone can see and trace out develops a statue with a form or expression that may be an inspiration to the people of all times to look upon and to meditate on.

The telephone and the locomotive, for the quick transmission of thought and of material bodies, were not formed by nature. They are composed of bits of iron, steel, copper, brass, wood, and rubber, and in their operation water and coal are used, but it was the master mind who saw these things in certain relations to each other, like the sculptor sees the image in the marble, that has produced and perfected these important tools of modern times.

The inventor benefits by the thoughts of others, by their study of the properties of material, and brings out and harmonizes these properties of matter, their strength and their weaknesses, compelling nature to administer to his needs.

In this study of material laws and forces, in the creative work that has been done in transportation, mining, metallurgy, manufacture, in commerce and in business it is the master minds in many different subjects and along many lines that have built up the possibilities of modern life. In the fierce competition in the advancement of the people and of their interests, specialists have been developed who have been trained and educated along rather narrow lines, by working intensively with a certain kind of material or with a certain tool or implement to develop their highest efficiency. It would be folly for one to purchase an iron foundry for the manufacture of paper goods or a cloth factory to manufacture hardware, nor would a paper manufacturer select a man of the same training or capacity as the cloth manufacturer or the hardware manufacturer would require.

In business and in the commercial world in all its branches, engines, materials, and men are being classified and organized more and more and are being so used as to attain the highest efficiency in production or service. Agriculture, the oldest as well as the largest of all our industries, is the most backward in its development. This is partly because the things appear commonplace and partly because the potential possibilities seem less spectacular and less remunerative for personal endeavor. Through force of necessity, due to increasing density of population, improvements have been made in increased production per acre and per man of field crops and, through personal interest and inventiveness, in the breeding and care of live stock as well as in the improvement of fruits and vegetables. To this extent, then, agriculture is being classified and organized. There are certain master men and classes of men who have classified animals and have developed them for a higher efficiency each in a line to which they are best adapted. The men who have developed cows which produce their own weight of butter fat or twenty-five times their own weight of milk per annum are not the men who have developed hens that lay 250 or 300 eggs per year. We are developing men who are specialists in the care of each variety of animal, who can see potential possibilities, who recognize the promise and who are steadfastly searching out the weaknesses in order to overcome the menace and to pass over the line set by natural forces uncontrolled.

In the development of agriculture, as in the development of industries, the soil which is the factory containing the raw material out of which plants and animals are developed must be classified and organized for its most efficient use and development. Not only must different soils constituting different factories be organized but men who operate them must be classified with the soil to attain the greatest efficiency. Such a classification of the soils of the United States is now being made by the soil survey. The smallest unit of this classification is called a soil type.

The soil type as recognized in the soil survey must have within narrow limits the same color characteristics in the surface and subsoil throughout its extent. It must also have the same kind and grade of mineral material forming the skeleton, derived from the same sources, and formed through the same agencies throughout soil and subsoil and throughout the extent of its occurrence. It must have approximately the same amount of tendons, muscles, and colloidal linings which affect the physical properties and it must have the same respiratory and circulatory systems as shown by the general drainage conditions. Its digestive system may vary considerably according to the past usage.

Soil types differ from each other in their potential possibilities as the Holstein cow differs from the Jersey or as one type of animal may differ from another. They differ from each other as different factories and mines or as different metals in their potential capacities. These differences in potential capacities of soil types are no more understood or realized than the potential capacities of our present industrial materials were 150 years ago. They are beginning to dawn upon us now as dawned industrial development at the beginning of the 19th Century.

A single soil type requires a life time of experience to develop the efficiency that it is possible to obtain with our present knowledge. The older countries of Europe have shown that the experience of several generations is still better and means a greater efficiency. This is illustrated by the efficiency of the English gardener whose ancestors have occupied the same soil for several generations. It is illustrated by the experiences in Japan where the older soils handed down through many generations from father to son are the best understood, the best regulated, and the safest soils to use.

The early Roman writers recognized the importance of the soil type, of the difference in adaptation of different soil types to different crops, and their requirement of different treatments and methods of cultivation and of rotation. In this country we have come to recognize the peculiar adaptation and dependence of certain soils for certain crops as in the case of commercial potatoes, of tobacco, of fruits, of the truck crops and of pineapples. Thus is the dawn breaking on the classification and organization of man and soils which marks the beginning of intensive agriculture in its true sense and marks the beginning of the development of agriculture comparable with the development of industrial life.

The soil type has its mysteries, its promise and its menace as well as the desert. It has its powers and its weaknesses only through the study of which can the master man hope to progress beyond the line set up by nature to retard the fainthearted or the inexperienced.

To combat these adverse forces of nature and compel an increased efficiency to supply the needs of the people, man has a few implements of tillage with which he can drain and cultivate the soil; a limited knowledge of crop rotation, of seed, plant selection and fertilizers and with these he must contend with nature and win from nature an unwilling consent to meet his demands.

A very pretty story has just been issued by the Department of Agriculture showing how nature has been thwarted in the case of the pineapple crop of Florida. Pineapples there are grown on a very loose incoherent sand that is quite unfit for the staple farm crops. This sand is manured quite heavily with one or several tons of commercial fertilizers per annum. For three or four years the pineapple thrives and gives remunerative crops after which the crops begin to languish and to fail. The scientists of the Department have found that this is due to nematodes or minute parasitic groundworms in the soil. These attack the pineapple plant through its fine feeding roots and produce a disease known as red wilt. The food thus furnished by the pineapple is evidently so agreeable and nourishing that the nematodes have increased in countless numbers. The remedy suggested is to plant the fields for at least two years with Natal grass or the Iron variety of cowpeas which furnishes a food that the nematodes do not like and for lack of proper nourishment in the juices and excreta of these plants die of starvation leaving the land in condition for pineapples again to be grown.

The continual growth of pineapples for a long series of years has thus disturbed the digestive processes and agencies in the soil, so that other crops must intervene to bring the land into condition again. Few soil types are able to remain in proper condition under the continuous cultivation in a single crop of any kind. Either a resting period or a rotation of crops is necessary to maintain the soil in condition. Is it any wonder that a farm runs down in a few years by unintelligent treatment where the menace and the threat of nature are fulfilled, and the man retires with the consciousness that he has failed to meet the menace and has been overwhelmed by the uncontrolled forces of nature?

The same thing happens when the care of a cow in high milk production is turned over to an unsympathetic man who does not understand her nature or her requirements. The entire disposition of a young person or an animal of any kind may be changed by a word unwisely spoken, by an injudicious act di-

rected against them, by uncongenial surroundings, treatment, or food, and the efficiency of the person or of the animal thereby be greatly impaired.

Every act of the man in draining, plowing, cultivating, seeding and harvesting affects the digestive, respiratory, and circulatory system of the soil either favorably or unfavorably. The soil type is not a simple, inert material; it is living and has vital forces which react on each other. Experience in the handling of these forces in a single soil type with such knowledge and experience as may be gained from others is just as essential to success in agriculture as it is in any line of industrial work. The soil survey has mapped something over 1,500 different soil types. Some of these are unimportant because of their small extent. Some are at present unimportant because of our present limited number of crops and there seems to be none that are adapted to the peculiar soil conditions. Some are at present unimportant because of their location under arid or mountainous conditions or inaccessibility to market for the products for which they are especially adapted. Several hundred of these soil types are of great importance because they produce the bulk of our crops and animals. Some of these soil types exist only in the South or in the North where climatic conditions and the length of the season is a controlling factor in crop production. What limitless possibilities are thus presented in the development of agriculture when soils, crops, animals and men are further classified and organized as they have been in industrial lines.

Each soil type is a distinct, organized entity — a factory, a machine — in which the parts must be kept fairly adjusted to do efficient work. It is not advisable that an attempt be made to make soil types equally productive for all crops. The difference in the properties of wood, steel, copper and iron when understood and made use of has made it possible to bring the arts and industries into their present complex relations to life. The important thing in agricultural development is to understand and utilize every difference in these soil types, to have them fulfill each their most important function for the good of society. The vision and the promise of what may be when these different forces of nature are better understood and properly utilized are immense.

We have been taught that the soil requires only to be fed with a few simple elements such as potash, phosphoric acid and nitrogen in suitable forms, as though the soil was a static thing. If this were so why preach about " intelligent cultivation; " why breed disease-resistant plants; why worry about the adaptation of soils for tobacco, for pineapples or for sugar corn?

The modern concept of the soil recognizes a digestive system that is influenced by the circulatory and respiratory systems and the skeleton of the soil itself. The digestive system is dependent upon the number and kind of bacteria, the oxidation process, the enzymes, the insects and above all by the organic food which is supplied to these digestive agents; namely, the kind and association of plants that are grown. It is dependent upon and influenced by the amount and character of the cultivation, which is the only way we have of exercising the soil as we exercise an animal.

The digestive system in a soil type and the products derived therefrom may be highly deleterious to certain crops. A man-eating animal like the lion would starve to death on the food required by an antelope. This marks the difference in the digestive system of the two animals. Certain persons can not digest butter fat; others can not digest an egg. A too narrow diet may induce scurvy or other diseases of the human person and may greatly reduce the efficiency of animal production.

In medieval times when little attention was given to cultivation and the exclusion of weeds, where animals were small, undernourished and relatively inefficient, where the open-field method of cultivation made it impossible to vary crops at will, the soils were in a very low state of productivity. Under a more settled method of land tenure with increasing density of population, with the teachings of the principles of careful husbandry, men resided on a single soil type until they began to know and understand its requirements. Then and not until then were the lines that nature had laid down passed and the soil made to produce more effectively for mankind. As already stated the Census of 1910 showed that 54 per cent of the farmers of this country had been on their farms, that is presumably on a single soil type, for a period not exceeding five years. What would be expected of the efficiency and productive capacity of a man in industrial work who changed his occupation and the character of his tools as often as this? First he would appear as a dentist with dentist tools, then as a laborer in a blast furnace, then occupying a position in a cloth mill, always shifting and always changing but not exceeding five years in any one occupation. He would be a jack of all trades and efficient in none. This is the condition of agriculture to-day with the majority of men who handle these soil types. The highest efficiency can be expected only of those who remain constant in their effort to understand a single soil type.

The physician investigates and treats the diseases and disorders of man whatever his occupation or whatever his nationality. The soil scientist likewise may study and treat the disorders of the soil of whatever type the soil may be for there are certain principles that run through the soil disorders as there are certain principles that run through the disorders of mankind, but the real experience in the handling of the soil type, as in the handling of a particular breed of cow, of horse, of sheep or of other animal, must be acquired by constant and diligent observation and experience.

The Endurance of the Soil

How long the soil will last and continue to produce satisfactory crops is a question that has been asked over and over again in the past ages. There are still some who believe the soil will last only a comparatively few years unless certain "plant food" elements such as phosphorus and potassium are returned to the soil in proportion to the amount removed from the farm by crops. This limits the natural capacity of a soil to produce to, the actual mineral content as of to-day with a decreasing natural capacity as time goes on and as crops are raised and removed from the farm. This view of the static properties of a soil is gloomy in the extreme for in case of inability to artificially maintain the supply of plant food a man might take one of two extreme views. In the interest of future generations he might think it advisable to leave his talent buried in the soil or in disregard of future generations he might say, let us " eat, drink and be merry for to-morrow we die."

There are many reasons for believing, however, that the soil has a regenerative power that will prolong its life indefinitely and that the ability to continue to produce crops is dependent solely upon the knowledge and skill of the man who works the soil. Such a view is almost forced upon us by historic evidence presented by the older cultivated soils of Europe and Asia. In the past three hundred years through denser occupation and improved methods, which have come about through force of necessity, the yield of wheat per acre in England, France and Germany has increased from about 12 bushels to 28 to 32 bushels. These lands had previously been occupied for agricultural purposes for one to two thousand years. The old Greek philosophers nearly three thousand years ago were speculating on how long the soils would last for the increasing population of the world. The limestone valleys adjacent to Athens are still producing satisfactory crops and so far as records can be obtained and be relied on are producing larger yields per acre than in the older days.

The country of Roumania which has always used primitive methods and which has not the word fertilizer in its vocabulary is still the granary of southern Europe, as it was when its history began, when for hundreds of years it was fought for by the Turks and by the Romans for the supply of grain (principally wheat) for their people.

It is true that in all ages certain soil amendments, such as lime, marl, fish, seaweeds, the bones of animals slaughtered on the farm and excrement from man and from animals, were recognized as having influence on the soils and crops. The natural phosphate deposits, the potash deposits and the nitrate deposits forming the basis of our modern fertilizer practice were undiscovered and unknown until quite recent years. It is quite impossible to conceive that any plant foods were imported into a country like Roumania up to the present.

The question as to how the people in the older centers of civilization have been fed, and the comparison of the soil types and soil composition which they have occupied with the newer soils of North and South America is vastly important, to settle once for all this vital problem of the continuance of soil productivity under the influence of man and his requirements, as well as to determine the methods he has used in maintaining the food supply of the world.

A review of the literature fails to show that there is any signicant difference in chemical composition as a result of the continued use of the soil for thousands of years. The question can only be definitely solved, however, by a systematic study of the soils around the older centers of civilization, such as London, Paris, Madrid, Rome, Constantinople, in Roumania, in India and around Pekin and Tokio. In Japan they consider their older soils the more valuable.

It may be broadly stated that were it not for the circulation of water within vast depths of the earth's crust we would have no workable deposits of any of the metals such as iron, copper, lead, tin, chromium, gold, platinum or even of lime, phosphates, or petroleum. These materials with the exception of petroleum were originally contained in the molten magma of the earth and in the igneous rocks resulting from the cooling of the same. Most of them are present in only small proportions and are only very slightly soluble in water. For instance lead is contained in igneous rocks to the extent of .004 per cent, zinc .009 per cent, and copper .006 per cent. They are present in ordinary soils to about the same extent. Through various processes of chemical solution and reactions and differences in solubilities of the various compounds they form, these metals have been completely separated from each other, carried up to or near the

·th where, under other conditions, of which we
ɔthing, they have been deposited in workable
ımense proportions at different places on the
ʌt other points on the earth's surface conditions
ɔr their precipitation and they wander up and
rculating waters in an unending search for a
hat a vast amount of water must have been
ınsportation to the surface and how complex
ɔf separation and final segregation have been!
ss has been used for the separation from the
he lifting of the material to the surface; the
ɔitation and segregation of our iron and

ron in some of our soil types is a familiar and
n of the movement of this material in soils.
eries of soils occurring on the Atlantic sea-
marshy and contain a large amount of organic
rowth and retarded decay of the vegetal re-
ım the luxuriant growth of certain kinds of
ide of iron which the soil originally contained
through the influences of decaying vegetation
ble ferrous form which disappears through
subsoil a characteristically white color. As
ated and drainage and aeration are estab-
orfolk, Orangeburg and Greenville types of
rrous iron coming up to or near the surface
again to the insoluble ferric oxide of iron

tions. In the Great Plains the calcareous material rises in the form of the bicarbonate of lime which is quite soluble but which changes on approaching the surface to the more insoluble normal carbonate of lime which remains near the surface as the rainfall is not sufficient to carry it down as fast as it accumulates. In the arid regions, where the rainfall is less than ten inches per annum, we have an accumulation near the surface of notable quantities of the most soluble salts such as sodium sulphate and magnesium sulphate with a smaller proportion of the more insoluble lime salts.

The mechanism of these complex forces of nature and the extent to which they are effective are difficult to understand and have not yet been worked out for lack of methods or sufficient observations to trace the movements that take place.

We know that part of the rain which falls runs off from the surface of the earth directly into the rivers and the ocean. Part of it passes down through the soil and runs off through the rivers and streams. Part of it is evaporated from the surface or is transpired by growing plants. There is, however, a considerable part which we believe enters and passes down into the lower depths of the earth. It is this part that enters the earth that is particularly interesting at this time. We know that it passes down considerably below sea-level. Whether it ever gets down to the region of the molten magma we do not know, but it seems highly probable. We also have evidence through the accumulation of the metallic ores that vast quantities of water must be ascending from great depths in the earth. There must be, there-surface of the earth where, under other conditions, of which we know little or nothing, they have been deposited in workable beds often of immense proportions at different places on the earth's surface. At other points on the earth's surface conditions are unfavorable for their precipitation and they wander up and down with the circulating waters in an unending search for a resting place. What a vast amount of water must have been used for their transportation to the surface and how complex must the process of separation and final segregation have been!

The same process has been used for the separation from the original magma, the lifting of the material to the surface, the infiltration, precipitation and segregation of our iron and phosphate deposits.

The shifting of iron in some of our soil types is a familiar and striking illustration of the movement of this material in soils. The Portsmouth series of soils occurring on the Atlantic seaboard are wet and marshy and contain a large amount of organic matter from the growth and retarded decay of the vegetal remains resulting from the luxuriant growth of certain kinds of plants. The red oxide of iron which the soil originally contained has been converted through the influences of decaying vegetation into the very soluble ferrous form which disappears through leaching leaving the subsoil a characteristically white color. As these soils are elevated and drainage and aeration are established, as in the Norfolk, Orangeburg and Greenville types of soil, we have the ferrous iron coming up to or near the surface where it is changed again to the insoluble ferric oxide of iron giving a yellow color to the subsoil of the Norfolk series and a red color to the subsoil of the Orangeburg and Greenville types, which are older and have accumulated a greater amount of the red iron oxide.

In the semi-arid soils of the Great Plains, where the rainfall is between ten and twenty inches per annum, we have a notable accumulation of calcareous material which is seldom found east of the Mississippi River, where the rainfall is thirty inches or more and where the frequent flushings prevent such accumulations. In the Great Plains the calcareous material rises in the form of the bicarbonate of lime which is quite soluble but which changes on approaching the surface to the more insoluble normal carbonate of lime which remains near the surface as the rainfall is not sufficient to carry it down as fast as it accumulates. In the arid regions, where the rainfall is less than ten inches per annum, we have an accumulation near the surface of notable quantities of the most soluble salts such as sodium sulphate and magnesium sulphate with a smaller proportion of the more insoluble lime salts.

The mechanism of these complex forces of nature and the extent to which they are effective are difficult to understand and have not yet been worked out for lack of methods or sufficient observations to trace the movements that take place.

We know that part of the rain which falls runs off from the surface of the earth directly into the rivers and the ocean. Part of it passes down through the soil and runs off through the rivers and streams. Part of it is evaporated from the surface or is transpired by growing plants. There is, however, a considerable part which we believe enters and passes down into the lower depths of the earth. It is this part that enters the earth that is particularly interesting at this time. We know that it passes down considerably below sea-level. Whether it ever gets down to the region of the molten magma we do not know, but it seems highly probable. We also have evidence through the accumulation of the metallic ores that vast quantities of water must be ascending from great depths in the earth. There must be, therefore, a continual movement downward through the larger spaces between the soil grains and a continual upward movement in the finer capillary spaces and in the colloidal material or there must be a continual ebb and flow in the movement of the ground water from and to the surface of the earth extending down to great depths.

What obscure physical forces are involved in this process we do not know. What obscure chemical changes are produced by the mingling of the descending and ascending waters or the length of time required to transport material in this way we have no certain knowledge and at present it is mainly a matter of speculation. We do know this, however, that our shale rocks which have been consolidated from material that has been subjected to all the agencies of weathering, to the leaching of rain, to the ocean waves and currents, are so similar in their chemical composition to the igneous rocks which have not been subjected to these agencies of weather that they can not be distinguished on the basis of the chemical composition. This would seem to show that in spite of all the vast forces which tear the rocks asunder and separate them through rain, leaching, and other agencies that in the great order of things there are compensating forces which tend to maintain certain equilibrium conditions or which definitely determine for the time being concentration of materials at certain places on the surface of the earth.

It appears from investigations and general observations which have been made that the average chemical composition of the soil moisture is sensibly constant in our soils and it appears that the concentration at the surface is somewhat greater than in the lower depths. This seems reasonable to expect as the water which reaches the surface from below and jumps off into the atmosphere must leave its burden of dissolved material at or near the surface of the earth. If, however, the solubility of the material which is left behind is not sensibly changed the recurring rains which enter the soil would take up the burden and tend to redistribute it in proportion to the amount of rain which falls.

The significant thing to us is that the earth's waters appear to carry a rather constant supply of all of the mineral elements which would include lime, potassium, the phosphates, copper, tin, and gold, always wandering from place to place in the soil until they find rest at or near the surface through a change in their solubilities when they are precipitated and accumulate in beds.

It appears from the most thorough investigations that it has been possible to make by geographers and hydrographers that the annual loss of soluble materials by leaching which have been carried into the rivers and thence into the ocean amounts to about 272 pounds per acre per annum. Of this about 5.79 pounds represents potash and 0.54 pounds represents phosphoric acid. These forces have been operating through millions of years and were there no replacements from the deeper depths of the earth it would be easy to calculate that in a comparatively few years the surface soils would be denuded of these constituents. Such, however, is not the case. Otherwise the soils would be unfit for agricultural use. However, this whole question will have to be reviewed as the concurrent losses of silica, alumina and iron in colloidal solution have heretofore not been recognized.

It has been estimated from the average yield and chemical composition of all the crops of the United States that the usable portions of these crops, that is the grain or the hay, contain on the average, per acre, about 14.5 pounds of potash and 10.6 pounds of phosphoric acid. A large proportion of these crops are fed to animals or otherwise consumed and left upon the farm. It is impossible to even make an intelligent estimate as to the amount of these elements actually removed from the farms of the United States. The problem, therefore, that presents itself is whether the upward movement of potash and of phosphoric acid from depths of the earth needed to replace the loss through seepage is sufficient also to supply and maintain in the soil enough plant food for the growing crops.

The historic evidence above referred to, which will be more fully elaborated hereafter, of the continued use of soil for thousands of years in the older countries of Europe and of Asia clearly indicates that the soils have a sufficient regenerative power to supply the loss from leaching and supply the additional toll which man has taken for his own needs.

It has been assumed in the past that the exhaustion of soils was due to the depletion of the available phosphoric acid, potash, and nitrogen and that the use of commercial fertilizers is justified on this ground alone. We have seen that the soil has very complicated functions which react on one another and that these functions of the soil must be kept constantly regulated and in tune to give the soil its greatest efficiency. We have seen that the ordinary fertilizer materials and soil amendments may affect both the physical condition and the digestive operations in the soil and it is therefore a grave question as to whether the fertilizer acts mainly as a direct source of food to the plants, or indirectly in maintaining a proper balance in the functional activities of the soil. The one is a simple thing that has not been satisfactorily demonstrated; the other is a complex thing, corresponding in complexity to the functional operations in the soil itself, and will require years of research to properly understand. In general the forces of nature appear more complex and mysterious the more we understand them. The simple solutions generally mark a complete misunderstanding and lack of knowledge.

A drop of water seems one of the most commonplace things in nature, but the lifetime study of many master minds has only begun to show us that it is one of the most complex and mysterious things that nature has devised.

What human mind to-day can predict or even dream of the possibilities of production when these mysteries of nature are unravelled, when we have obtained control and can exercise control on the forces of nature in the soil to compel them to work for the interest and necessities of our people.

CHAPTER II

THE IMPORTANT SOILS OF THE UNITED STATES

Soil types differ as much in the economy of nature and of man's use as do animal types but the functional activities have not been revealed so clearly, have been in fact hidden from us in the past, and it is essential to our future prosperity that these things be searched out and revealed, so that we can make an intelligent attempt towards controlling them and better utilizing them according to their natures and properties.

In describing the soils and their peculiarities reference is made to the climatic conditions of rainfall and temperature under which they have developed their present soil characteristics. The small map below shows in a general way the climatic conditions under which the soil characteristics have been developed. From the eastern coast of the United States to the eastern boundary of the Pacific Coast Region the temperature lines run in a general east and west direction. In Europe both the temperature and the rainfall lines run in a general east and west direction and, in proceeding south from the north of Europe, as the temperature increases the rainfall decreases.

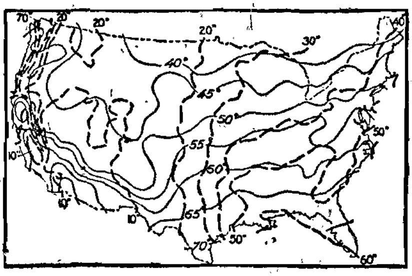


FIG. 1. Mean annual temperature and precipitation lines in the United States. Note that the impingement of these lines is such as to give great variation of climatic conditions in different parts of the country.

In the United States however the lines of equal rainfall are fan shaped, coming together within the borders of the State of

Texas. The line of 60 inches of rainfall bends sharply and only touches the coast in a small area in southern Louisiana and in the extreme south of Florida. The line of 50 inches of rainfall originating in east Texas swings eastward and leaves the coast not far from Norfolk. The line of 40 inches bends eastward more gently and emerges in Maine. The line of 30 inches has a still more gentle curve towards the east and emerges in the Great Lakes region. The line of 20 inches proceeds almost directly north while the line of 10 inches swings sharply to the west. This gives a great range of climatic conditions of temperature and rainfall, and consideration must be given to all of the combinations thus formed in considering soil characters.

Soils of the Appalachian Mountain and Plateau Province

The extreme eastern portion of the Appalachian Mountain and Plateau province, known as the Blue Ridge Mountains, consists merely of an uplift of the western edge of the Piedmont Plateau forming a pronounced ridge with generally very steep mountainous slopes, single mountains attaining a height of from 4,000 to over 6,000 feet above sea level. The rocks underlying these mountains are the same highly crystalline and metamorphosed rocks constituting the Piedmont, particularly granite and gneiss. This ridge is separated by the great valley of Virginia from the Appalachian Mountains and Plateau proper, which are composed of sandstone, shale, and limestone, which at one time in geologic history constituted a coastal plain into which soil material was deposited from rivers with their mixing and segregating powers and which were further acted upon by

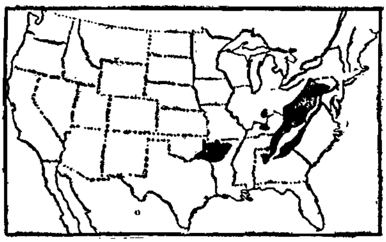


FIG. 2. Appalachian Mountain and Plateau Province.

ocean waves and currents. From the condition of an ocean floor upon which limestone beds were developed, the coarser materials having been consolidated into sandstones, the finer materials into shales, the whole was elevated above the ocean level by great earth movements into a succession of ridges and high plateaus.

The detached portion of the region centering mainly in northwestern Arkansas is underlain mainly by sandstone, limestone and shale, with relatively small isolated areas of crystalline rocks, with no such marked differentiation as to position occurring as exists in the eastern part of the province where the limestone valley makes a sharp division between the crystalline and the other classes of material. Much of this province is still too rough for agricultural operations.

Two soils have been selected to illustrate the dominant agricultural soils particularly of the eastern part of the province, namely the Porters and the Dekalb.

The Porters Soils. — The Porters soils are derived from the igneous and metamorphic rocks, particularly gneiss and granite. They occur on the more gentle slopes particularly in the coves and on the flat tops of ridges. They have a brown surface soil and a yellowish-brown to reddish-brown friable subsoil. On the steeper slopes of the mountains where erosion is strong and rapid the Porters soils can not exist and the material is red, like the heavier soils of the Cecil series. They have been developed from the same red material in areas of such gentle contours that incipient erosion has taken place which has been sufficient to remove much of the colloids carrying the red oxide of iron leaving the coarser sands and silt, without the distinguishing red color, making them very friable and easily worked. On account of the steep and rough topography generally interposed between them and the valley floor access to the Porters soils is usually difficult and these soils are not used to any considerable extent for general agriculture.

This apparently slight and superficial difference in the color and the texture of these Porters soils has resulted in a very important influence on their commercial adaptation to special crops, especially for apples. At favorable altitudes and under favorable exposures as regards air drainage they are preeminently adapted to the production of apples and in some localities the Albemarle Pippin does remarkably well. Some of the higher lying areas of the Porters produce an excellent growth of bluegrass which affords excellent pasture. Irish potatoes and cabbage do remarkably well and have a superior quality. The Porters soils are naturally productive, as they possess good respiratory and circulatory systems and their digestive system seems particularly adapted for certain crops.

The Dekalb Soils.—The Dekalb soils are derived from the sandstones and shales of the Appalachian region proper. They have a gray or yellowish-gray surface soil and a yellow subsoil. Owing partly to their isolated position, partly to their rough topography and partly to the character of the soil material itself, they are not highly developed for agriculture.

Locally they are important for the production of fruit, especially of late peaches. Rye to some extent takes the place of wheat, and buckwheat comes in as a crop of local importance. They furnish a considerable amount of cheap pasture for the raising of cattle and locally for sheep. The soils are not adapted to corn, partly because of the elevation and partly because of the shortness of the season. These soils are not particularly adapted to wheat. The principal agriculture in the way of general farm crops of the region is carried on on the valley soils, either in the small limestone valleys occasionally found or on the reworked material forming such soils as the Huntington, Pope and Moshannon in the stream bottoms which occur throughout the area like fingers. The respiratory and circulatory systems are not very favorable to agricultural crops and the digestive system is therefore not what could be wished. In some of the more northern areas where clover can be grown these soils have been brought to produce fairly good yields of corn and wheat.

There is apparently a marked difference in the digestive systems of the Dekalb and Porters soils, as indicated by the different classes of crops they normally produce.

Soils of the Atlantic and Gulf Coastal Plain Province

Six groups of soils have been selected as having a dominant influence on the agriculture of this Province, namely, the Portsmouth, Norfolk, Orangeburg, Sassafras, Crowley, and Houston. They have all had a common mode of origin. The material of which they are composed has previously existed in soils of other soil provinces. This material has been transported by rivers which have tended to mix materials from different sources and yet have segregated these mixtures according to the flow and floods of the streams. The delta plains and terraces formed by the deposition of the material from the river water have been more or less subjected to the action of ocean waves and currents which has further tended to segregate the material, leaving mainly the sand deposits of the Atlantic Coast as the clay has been drawn off by the ocean currents, while in the quieter waters of the Gulf Coastal Plain clay material has been deposited from the currents of the Gulf Stream. We have, therefore, on the Atlantic side dominantly sands and sandy loams, while on the Gulf side we have the heavier loams and clays.

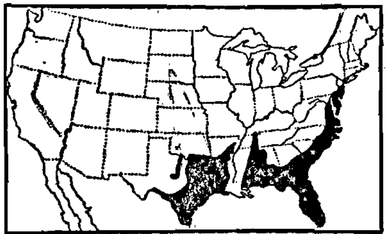


FIG. 3. Atlantic and Gulf Coastal Plain Province.

From the Potomac River southward to central Alabama the material has been derived mainly from the crystalline rock material of the Piedmont Plateau. From the Potomac River northward material has also been brought in from the Appalachian Mountain and Plateau sandstones and shales, and from the glacial material farther north which has a limestone admixture. It is the influence of this transported shale, sandstone, and glaciated material that limits the occurrence of the Sassafras soils to the portion of the Coastal Plain lying around and north of the Potomac River drainage.

From the Potomac River southward to the Alabama River the drainage is mainly from the Piedmont Plateau and in this area the Norfolk, Orangeburg and Portsmouth soils are largely developed.

From central Alabama to the eastern boundary of Texas we have the drainage from the limestone valleys which discharges from the Alabama drainage systems and the material carried by the Mississippi drainage, involving the entire east-central portion of the United States up to the Canadian boundary line, crossing the sandstone and shales of the Appalachian, the limestone material in Kentucky, Tennessee, and Missouri and the glacial and glacial lake material farther north. It is in this portion of the Coastal Plain that the Crowley soils are found and that one important area of the Houston soils occur.

In the Texas portion of the Coastal Plain the material has been brought down from the sandstone, shale and limestones of the Great Plains.

The Portsmouth Soils. — Among the youngest soils of the Atlantic Coastal Plain are the Portsmouth, which predominantly lie only slightly above sea level. These soils have been formed under an average rainfall of from 40 to 60 inches and under an annual mean temperature of from 45° F. in the northern part to over 70° F. in the southern part of the area occupied. The drainage is exceedingly poor, the material being almost constantly wet and usually saturated. The soil, therefore, has not as yet established a respiratory system. It is like an animal whose lungs are filled with water. It has not an adequate circulatory system and these have had the effect on the digestive system that only such organisms and biochemic reactions and chemical changes as can take place in the practical absence of oxygen have developed, and the only vegetation that has been supported has been a dense growth of aquatic types of trees and herbaceous vegetation including sedges and rushes. Under these conditions where organic material decays very slowly there is a great deal of organic matter accumulated in the soil and the soil is generally a dark brown or black with the subsoil mottled gray and yellow. The subsoil is likely to be compact and impervious. The red oxide of iron which is so characteristic of the southern Piedmont material has been changed under these conditions to the ferrous form which is quite soluble and which is gradually lost through the imperfect drainage system changing entirely the appearance of the material from which it was derived.

These soils in their natural condition have a very limited use for any of our valuable crops. The only way they can be handled is to perform a major operation, which we call drainage, to relieve the soil of excessive water and reestablish an adequate respiratory system which in time will change the digestive system so as to fit it for the production of such crops as corn and such truck crops as potatoes, cabbage and strawberries. In their natural condition they afford a cheap pasture for cattle or when the functional activities are properly balanced through the slow process of nature in elevating these soils or the quick operations of the engineer in relieving the congestion of water and establishing a suitable respiratory system they become valuable soils for a few selected agricultural crops.

In operating on the Portsmouth soils the past history of the native vegetation must be considered, for there are certain areas which have been occupied by a class of vegetation which does not easily respond or react to the improved respiratory and circulatory systems of the soil, as the kind of organic material left by the native vegetation is not easily or quickly digested by the biochemical agents which have developed in that peculiar food material.

The Norfolk Soils. — The Norfolk soils lie generally parallel to the Portsmouth, but at a higher elevation on the Coastal Plain, affording them more perfect drainage. The material of the Norfolk soils has been derived mainly from the Piedmont material carried by rivers and subjected to the action of ocean waves and currents which have removed much of the finer silt and colloidal material leaving a range of soils from coarse sands to fine sandy loams. The soils have a gray top soil and a yellow friable subsoil. The probabilities are that these soils have passed through the stage of the Portsmouth and through natural changes have developed into their present form. The yellow color of the subsoil, as distinguished from the white or gray color of the subsoil of the Portsmouth, marks a beginning of the return of the iron oxides from the lower stratum to which they were removed under the Portsmouth conditions. At the same time with the change of natural vegetation from grasses and sedges, which would tend to give a black color to the soil, to a forest growth the color of the soil has changed to a light gray. Thus the color of the soil is a very important indication of the functional activities within the soil, whether due to previous vegetative growth or to other causes.

The coarse members of the Norfolk series, particularly the Norfolk coarse sand which frequently occurs as sandhills on the inner side of the Coastal Plain, have such a weak circulatory system that they are inefficient for the support of valuable crops except in very limited and restricted positions.

The Norfolk fine sand, sandy loam, and fine sandy loam are the important soils of the series. The fine sandy loam has a greater extent and a wider range of agricultural adaptation than any of the other types. It is one of the most important cotton soils of the South. It is the dominant corn soil of the Norfolk series, although for this crop it has not nearly the capacity of some of the other soils which will be later described. It is an important soil for the production of truck crops where yield, rather than earliness of production is considered. In southern Virginia, the Carolinas and Georgia the deeper phases of this type are important in the production of bright tobacco. In southwestern Georgia and western Florida it is the leading cigar wrapper tobacco soil.

The Norfolk fine sandy loam is the most extensively used soil for market peanuts, the industry centering in southeastern Virginia and northeastern North Carolina. Further south it produces a cane syrup of good yield and bright color. The Norfolk fine sand matures truck crops earlier and has this advantage over the fine sandy loam as a special purpose soil under an intensive system of agriculture. The Norfolk sand is associated with the production of citrus fruit, vegetables and velvet beans in Florida and of watermelons in Georgia. The Norfolk sandy loam is associated with about the same agricultural interests as the fine sandy loam, but because of its somewhat coarser texture has not quite the productive capacity of that type.

The Norfolk soils which dominate the agriculture of the central Coastal Plain are preeminently special purpose soils. The United States has the largest extent of Coastal Plain of any country or any continent so far as is known. The Norfolk soils have relatively coarse textures and a relatively small amount of colloidal material and they, therefore, require the most intensive and the most careful treatment. They are not strong enough for the general farm crops of wheat, corn, and pasture or hay grasses such as are produced on the heavier soils of some of the other soil provinces. They require a lighter form of farm equipment. They are more dependent upon the application of manure and fertilizers.

There are thousands of acres lying inland from the modifying influences of the ocean climate or remote from transportation facilities which can not be used for special purpose crops that are still in forest or cultivated with poor success in general farm crops. There are other thousands of acres which through improper methods of cropping, of cultivation or lack of other care have decreased in productivity and been thrown out to the occupation of sedges or allowed to grow up in old-field pine or small oaks and allowed to revert to natural vegetation, to slowly recover through this resting period from the injudicious use or neglect of the years of occupation.

The Orangeburg Soils. — The Orangeburg soils may be assumed to have had the same general origin as the Portsmouth and Norfolk soils. They occur only in the southern part of the Coastal Plain at somewhat higher elevations than the Norfolk and generally on the western and northern side of the main Norfolk belt. They occur from the middle of North Carolina southward to Alabama and Florida under a mean annual temperature of from 60° to 70° F. and under a rainfall of from 40 to 60 inches per annum. These soils are more mature than the Norfolk soils. They have a gray surface soil and a red subsoil. The iron oxide which presumably was leached out when the soils were in the Portsmouth condition has been returned in full amount by the ascending waters from below and has been redeposited in the soil as the red ferric hydroxide rather than as the yellow ferric hydroxide occurring in the Norfolk soil. This has given the Orangeburg soils a rather higher content of colloidal material than is possessed by the Norfolk soils. This makes the Orangeburg soils somewhat stronger and more rugged than the Norfolk soils. While they are adapted to about the same range of crops they will stand more hard usage; they are somewhat more reliable under average conditions and are somewhat better adapted to the general farm crops. They are well adapted to cotton, but otherwise are special purpose soils for special crops.

The Sassafras Soils. — The Sassafras soils occur only in the northern part of the Coastal Plain, north of the Potomac River. They have been formed in much the same way as the Norfolk soils, but apparently have not been subjected to such severe treatment by the ocean, as the dominant types are the loam and silt loam. They have derived their materials in part from the Piedmont and Appalachian soil regions as have the Norfolk soils, but in addition they have had some admixture at least of the glaciated material farther north. They have taken on their soil character or have readjusted their soil character under a mean annual temperature of 50° to 60° F. and under a mean annual rainfall of from 40 to 50 inches.

They are brown soils with reddish yellow subsoils, with usually a substratum of sand or gravel. They have well-balanced respiratory and circulatory systems. They have a higher colloidal content than the Norfolk soils and have a well-developed digestive system. These soils are much stronger than either the Norfolk or the Orangeburg soils and in consequence are adapted to an entirely different type of agriculture. They require a heavier type of farm equipment, deeper plowing and can stand more hard usage.

The Sassafras silt loam especially is well adapted to corn, wheat, hay and pasture grasses, dairying and a limited amount of stock raising as seen in eastern Maryland, in Delaware, and in southwestern New Jersey. It is also adapted to fruit and vegetables, but as the vegetables mature later than on the adjoining Norfolk soils they are grown principally for canning purposes. The Sassafras sandy loam is especially adapted to peaches and small fruits and, together with the fine sand and sand, is adapted to the early truck crops but not to the heavier farm crops as their circulatory systems are not strongly enough developed to satisfy the heavier farm crops.

The Houston Soils. — The Houston soils occur in a long narrow belt running nearly across Alabama and Mississippi in the form of a crescent. They are much more largely developed in a north and south belt in Texas. When the Coastal Plain was submerged in these particular portions, marine shells or limestone deposits accumulated to a considerable depth without much admixture of material washed from the land surface. This deposition presumably took place in relatively quiet or protected waters possibly in sounds such as those in which heavy soils are accumulating to-day. This material on aging has developed into a highly calcareous marl which forms the substratum and parent material of the Houston soils.

The natural vegetation of these Houston soils has consisted of a dense prairie growth of grasses. These soils have matured under a mean annual temperature of around 65° F. and under a rainfall in the eastern part of 50 to 60 inches and in the Texas area of about 30 to 40 inches. As would be expected, therefore, with prairie conditions and in calcareous material the soils are black. The subsoils are light gray to light brown with a highly calcareous substratum.

The soils are very high in their colloidal content, suggesting strongly that soil colloids were brought in and deposited over the surface by slow moving currents of water at some stage in their development. The Houston soils are generally well drained giving them an adequate respiratory system and with the fine texture and high colloidal content a strong circulatory system and a correspondingly strong digestive system.

These are very strong soils, very plastic when wet from which they derive their local name of "black waxy lands." On drying they have a tendency to break up into small aggregates or granules, which permits of their cultivation where other types of material would bake into a hard refractory mass which would prevent or greatly hinder cultivation when the soils are moderately dry.

The Houston soils are considered among the most productive cotton soils, but this has become a crop of secondary importance in the eastern area because they are peculiarly adapted to alfalfa and to pasture grasses and forage crops and certain of the grain crops, and their use is turning more and more to heavy farm crops in which cattle and hogs and dairying have an important place.

The Crowley Soils. — The Crowley soils are confined to that portion of the Coastal Plain which has derived its material from the Mississippi drainage without much apparent disturbance during the period of submergence. They consist mainly of a skeleton of very fine material largely composed of silt and contain a large amount of colloids. They are very slightly elevated above sea level, have very poor drainage, have a very weak respiratory system and a very weak circulatory system. They have taken on their soil character under a mean annual temperature of about 65° to 70° F. and a rainfall of 50 to 60 inches or somewhat more.

They are very young and immature soils. The surface soil is gray. The subsoil is mottled gray and yellow and the substratum below 30 inches is red, gray and yellow. They have a considerable amount of iron concretions. The native vegetation consists of prairie grasses adapted to poorly drained heavy soils. The one crop that succeeds on the Crowley soils is rice and they form the typical rice soils of southern Louisiana.

Other Soils of the Atlantic and Gulf Coastal Plain. — The six groups of soils above described illustrate in a general way the dominant agricultural soils of the Atlantic and Gulf Coastal Plain provinces. There are, of course, a great many other classes of soils that have arisen because of the particular place they occupy. Many of them are immature and of very little value, while others are well developed and as productive as any of those described. They are described in all necessary detail in the soil survey reports of the various counties, but cannot be treated here for lack of space. They differ in agricultural importance because of local differences in the source of the material, the forces to which they have been subjected, their elevation above sea level, the temperature and rainfall conditions under which they have been developed, the character of the native vegetation and other facts, many of which are still unknown, which have given character to the soils of different parts of the Coastal Plain.

Soils of the Glacial and Loessial Province

Four soils have been selected as representative of the soils dominating the agriculture of this province: The Carrington and Miami, representing the ice-laid material, and the Marshall and Clinton representing the loessial or wind-borne material.

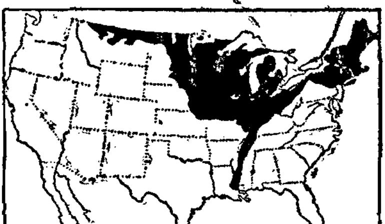


FIG. 4. Glacial and Loessial Province.

The northern part of the province is composed of ice-laid material and the southern portion, south of an irregular line extending from the southeast corner of South Dakota to Cincinnati, Ohio, is the area over parts of which the wind-blown material has accumulated to a sufficient depth to give a distinctive character to the soils.

The ice-laid material, as a whole, is a heterogeneous mixture from crystalline rocks, sandstones, shales and limestones. Locally there are areas in which one or more of these materials is lacking and there are areas in which the material is derived from a single kind of rock. These mixtures and combinations of rock material have impressed upon the soils characteristics that serve in a large measure to differentiate soil types. In the New York and New England portion of the province the glaciation has in places been thin and superficial and over a great variety of rocks, giving rise to a greater number of soil types than in the central and western part of the province where the soils are liable to be quite uniform over large areas.

The Carrington Soils. — The Carrington soils are derived from a mixture of granite, sandstone, shale, and limestone material which has been transported, mixed, and ground up by ice movements. The color of the surface soil is dark brown to black from the fact that it has had a prairie grass vegetation with an abundance of lime in the soil. The subsoil is a yellowish brown indicating that the ferric hydroxide is in the form of the yellow hydroxide rather than as the red hydroxide of warmer climates. The Carrington soils are underlain with a substratum of bowlder clay. These soils have developed their soil characteristics under a mean annual temperature of from 40° to 50° F. and under a mean annual rainfall of from 20 to 40 inches.

The Carrington soils have a medium to fine skeleton, having a rather high content of sand in the sandy types and silt in the silt loam and clay loam members. They have a rather high content of colloids but as a rule they are well drained. They have well balanced respiratory and circulatory systems and appear to have a very strong digestive system which marks them as very strong soils for the production of general farm crops. Within the climatic limits of the corn belt they are great corn soils with oats as the principal small grain and with hay and pasture grasses, the feeding of stock, dairy cattle and hogs constituting the most important industries. North of the corn belt spring wheat comes in as an important grain crop and the dairy industry becomes of first importance.

The Miami Soils. — The Miami soils like the Carrington have been developed from a heterogeneous mixture of rock material deposited by ice action. Unlike the Carrington, however, the native vegetation has been forest growth with a resulting light-colored soil. They have a brown surface soil and yellow subsoil and a substratum of calcareous bowlder clay. The silt loam and the silty clay loam, which are the important members of the series, have a fine skeleton with a high content of colloidal material in the subsoil. The surface soils have a much lower colloidal content and are generally easy to till yet requiring heavy farm implements and equipment. These soils can stand a great deal of hard farming.

The surface is gently to steeply rolling and as a rule the soils are well drained, have a very strong respiratory and circulatory system and a digestive system adapted to the heaviest type of farming known. On level or in depressed areas the respiratory system may be inadequate and the soils may require individual farm drainage systems.

These soils are equally adapted to corn and to winter wheat, to grasses for pasture and for hay and to dairying. They are not used so largely for the feeding of beef cattle or of hogs as in the case of the Marshall soils. They are preeminently the general purpose soils of the northern temperate zone, as developed in central and western Ohio, central and northern Indiana, southern Michigan, and over considerable areas in southeastern Wisconsin.

The Marshall Soils. — The Marshall soils are derived from material laid down by the wind. They have a fine skeleton composed largely of silt particles and carry a large amount of colloidal material. The native vegetation has been the prairie grasses and with the considerable amount of limestone or other calcareous material they contain this has given rise to a dark-brown to black top soil. They have a yellowish-brown friable silty clay loam subsoil. They have a gently rolling surface, are well drained, and have a well-balanced respiratory and a strong circulatory system and a digestive system adequate to the needs of hard farming without a great deal of attention being given to crop rotations.

They are preeminently the corn soils of the corn belt. They are not as well adapted to wheat, but large quantities of oats are produced in place of wheat. The Marshall soils are well adapted to the pasture and hay grasses and to dairying, but their principal use is in the production of corn for the feeding of live stock and especially of hogs.

The Clinton Soils. — The Clinton soils lying east of the Marshall are also derived from wind-blown material. They have a fine skeleton mainly of silt material, but unlike the Marshall the native vegetation has been a forest growth which has resulted in a light-brown soil with a rather compact yellow subsoil. The surface is gently to steeply rolling. The Clinton soils are generally well drained. They have a high content of colloidal material in the subsoil and a respiratory, circulatory, and digestive system that makes them preeminently adapted to winter wheat.

In this Middle Western territory, under nearly similar climatic conditions, the Marshall, Clinton and Miami soils show interesting differences in their agricultural adaptations which are apparently due to differences in their digestive systems. The Marshall soil is preeminently adapted to corn with wheat as a very secondary crop but with oats as the important small grain crop. The Clinton, on the other hand is predominantly a wheat soil with corn as distinctly of secondary importance, while the Miami soils are equally adapted to corn and to wheat.

Soils of the Glacial Lake and River Terrace Province

The Glacial Lake and River Terrace province occurs along the extreme northern border of the United States and lies entirely within the Glacial province. The material composing the soils of this province has been derived from the Glacial province having been carried and assorted to some extent by preexisting rivers and streams, forming terraces or old valley fillings, and partly from this same material worked over by the waves and currents of the old glacial lakes and segregated by these agencies much as the soils of the Coastal Plain have been separated by ocean action. With the contraction or complete disappearance of these streams and lakes the soil has been left to develop as old river terraces or lake beds.

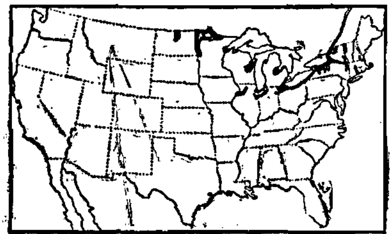


Fig. 5. Glacial Lake and River Terrace Province.

The present climatic conditions under which these soils have taken on their soil characters and now exist are from less than 40° F. mean annual temperature to about 50° F. and under a rainfall of from 30 to 40 inches from the eastern boundary of Minnesota eastward and under about 20 to 30 inches in the Minnesota and Dakota extension of the province.

Three soils have been selected to represent the dominant agricultural soils of this province, the Dunkirk, Clyde and Fargo.

The Dunkirk Soils. — The Dunkirk soils are the oldest and best developed soils of the three. They have a gray to light-brown soil and yellow subsoil. They have their greatest development in New York along the shores of Lake Erie and Lake Ontario. They are strong heavy-bodied soils in which the circulatory and respiratory systems appear to be thoroughly well-balanced. They have apparently a somewhat unusual digestive system which makes them dominant in the production of fruit, especially of apples, pears, peaches, cherries and in the production of grapes.

The heavier types are also well adapted to the production of corn and hay grasses and they are important soils for the feeding of cattle and for the dairy interests.

The Clyde Soils. — The Clyde soils are black with bluish-gray to yellow mottled subsoils, generally with a substratum of bowlder clay of unaltered glacial material. The deep subsoil or substratum is usually highly calcareous. They occur east of Minnesota under a rainfall of 30 to 40 inches. The Clyde soils have rather a weak respiratory system and a sluggish circulatory system which often has to be corrected by artificial drainage. When these are properly balanced they are dominant soils in the production of sugar beets, especially in Michigan, Ohio and Wisconsin, in the production of cabbage and onions, and over a large part of central Indiana and western Ohio and in the Saginaw Basin of Michigan, where conditions are properly balanced and the digestive system is just right, they are extensively used for corn and hay grasses.

The Fargo Soils. — The Fargo soils have been developed only in Minnesota and North Dakota under a rainfall of 20 to 30 inches and under a mean annual temperature not exceeding 45° F. The soil is black with a mottled drab, brown and yellow subsoil which is stiff and plastic and highly calcareous. The skeleton of this soil is composed of fine-grade material mainly fine sand and silt with a very high content of colloidal material. The soils are usually heavy and some of the heaviest, the gumbo soils, are exceedingly difficult to till. The Fargo soils have naturally rather a weak respiratory system and rather a sluggish circulatory system which frequently needs artificial drainage to bring about a proper balance. These soils constitute the great spring wheat soils of the Red River Valley. They are preeminently adapted to barley and are adapted also to oats and flax.

Soils of the Limestone Valley and Upland Province

This province presents itself in two markedly different physiographic features. The eastern extension is of a pure limestone which through solution has left a residue of the former impurities in the rock and forms a depressed area between the Blue Ridge and the Appalachian Mountains constituting the Great Valley of Virginia which extends from northern Alabama up into Pennsylvania and forms a depressed area in central Tennessee and Kentucky. The Highland Rim portion around the depressed area and the western extension of the province in the northern Ozark Region were formed of equally pure limestone containing a great many cherty beds, with the result that the surface is generally higher and much more rolling and hilly in character. Part of this area has such broken topography that cultivation is rendered difficult and locally impossible.

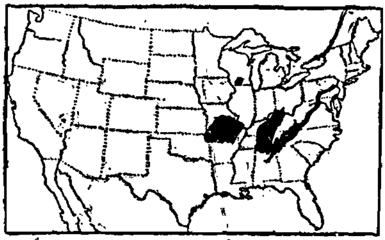


FIG. 6. Limestone Valley and Upland Province.

Two soils have been selected to represent the dominant agricultural soils of the province, the Hagerstown and the Clarksville.

The Hagerstown Soils. — The Hagerstown soils have developed from the pure limestone. The surface soil is brown and the subsoil reddish brown to reddish yellow. Limestone rock outcrops are not uncommon, but the soil itself is not calcareous. It has developed under a mean annual temperature of from 50° to 65° F. and under a mean annual rainfall of from 40 to 60 inches.

The soil has a fine-grained skeleton with a fairly large amount of colloid, especially in the subsoil. The soils have a strong body and well-balanced respiratory and circulatory systems. They require a heavy type of farm implements and will withstand any amount of intelligent hard farming. The Hagerstown soils have a digestive system which fits them for a wide range of crops. They are dominant in the type of general farming which prevails in the Lancaster Valley of Pennsylvania, in the Hagerstown Valley of Maryland, in the Shenandoah Valley of Virginia and in the central basin of Tennessee and the bluegrass region of Kentucky, where wheat, corn and pasture grasses, particularly bluegrass, are important and the fattening of cattle, the raising of horses and the dairy industry are dominant in the animal industries. In Pennsylvania alone they are dominant in the production of a cigar-filler tobacco, while in central and northern Kentucky they are dominant in the production of White Burley tobacco.

In the southern extension of the Shenandoah Valley and in other smaller valleys in north Georgia and north Alabama the color of the soil and subsoil changes to red and they are classed as Decatur soils. This color change is apparently similar to the change of color between the Chester and Cecil soils of the Piedmont Plateau, the red color of the Decatur soils apparently indicating that under the warmer climatic conditions the red iron oxide has developed rather than the yellow which has developed in the Hagerstown soils proper.

The Clarksville Soils. — The Clarksville soils are gray with a yellow subsoil, both containing an abundance of chert. They are developed principally in the southern part of the Great Valley, on the " Highland Rim " surrounding the central basin and the bluegrass region of Kentucky, and in the Missouri and Arkansas areas and constitute the upland limestone areas as distinguished from the valleys occupied by the Hagerstown soils. The Clarksville soils in their more level areas are more difficult to till than the Hagerstown soils on account of the large amount of siliceous and chert fragments.

The circulatory system is not as strong and the digestive system does not lend itself to so great a range of crops or to the satisfactory production of any of the general farm crops. It has, however, an important place in the production of the dark tobacco of Kentucky and Tennessee and locally in the production of strawberries, cantaloupes and peaches. In northern Alabama and Georgia they are used for cotton and in general agriculture they produce light yields of corn, wheat and hay. There are large areas still undeveloped or used for cheap pasture for the raising of cattle.

Soils of the Piedmont Plateau Province

The Piedmont Plateau province consists of igneous and usually strongly crystalline rock such as granite, of highly metamorphosed rocks such as gneiss, of rather slightly metamorphosed rocks such as mica schist and to a small extent of non-crystalline rocks such as the Triassic sandstones and shales. The southern Piedmont below middle Virginia consists mainly of the highly crystalline rocks such as granite with some gneiss, while the northern Piedmont is made up principally of highly metamorphosed rocks such as gneiss and the slightly metamorphosed rocks such as chlorite schist. The crystalline rocks, while probably not in the form of the original earth crust, are among the oldest of the rocks now existing. The present soil material has been derived from the weathering and disintegration of these rocks without any material shifting or intermingling of materials from other places.

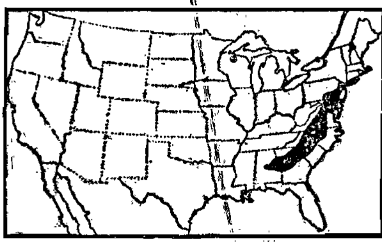


FIG. 7. Piedmont Plateau Province.

The soils have developed under a mean annual temperature ranging from 50° F. at the northern extremity to about 65° F. at the southern extremity of the province in central Alabama. The mean annual rainfall is about 40 to 50 inches. The surface is gently rolling and varies from about 300 to 1,000 feet above sea level.

Three soils have been selected as representing the dominant agricultural soils of the province, namely, the Cecil, Chester, and Penn. The Cecil soils dominate the agriculture of the southern Piedmont from middle Virginia where the mean annual temperature is around 55° F. while the Chester and the Penn soils dominate the agriculture of the northern Piedmont, where the mean annual temperature is somewhat lower.

The Cecil Soils. — The Cecil soils have a gray to red soil and a red subsoil. The gray soils occur on the level and gently sloping areas where the incipient erosion has washed out much of the fine colloidal material without much power to remove the larger grains of sand which thus accumulate as a mantle over the red clay, giving rise to the Cecil sandy loam. The red soils occur where the slope is sufficient to give the rain wash a sufficient impetus to remove the sand about as readily as it can remove the finer material. This gives rise to the Cecil clay loam. The original vegetation of the Piedmont Plateau was a forest growth, therefore, there are no black soils which might have been expected under a prairie growth of grasses.

The typical Cecil red clay has well-balanced circulatory and respiratory systems. The digestive system is apparently not so strong as some of the other soils of the United States, as it appears to be more delicate and to require more care in rotations and in fertilization to maintain a high degree of productivity. It is rather common to see fields that have been used for a few years and then turned out for a growth of pine and other trees to give the soil a resting period for recovery from the effects of improper cropping and cultivation that has been practiced.

The Cecil sandy loam is identified with that form of agriculture prevalent in the central portion of North Carolina, the western portion of South Carolina, northern Georgia, and central Alabama, where cotton is the dominant crop, with corn grown mainly for home use. Locally there is some production of peaches, and in North Carolina of dark tobacco. The Cecil clay loam, extending from central Virginia southward, is one of the important cotton soils from North Carolina southward. In southern Virginia it is dominant in the production of the Virginia type of export tobacco leaf, and in North Carolina in the production of domestic manufacturing tobacco. It is a much more difficult soil to work than is the Cecil sandy loam, and its full value has not been developed with the light equipment of horses and implements that is generally used. Its true place is for the production of corn, small grains, forage crops and tobacco, and for the fattening of cattle and dairying, as modified by the range of climatic conditions under which the soil occurs and by market and transportation facilities. It is an excellent soil for hay grasses rather than for pasture grasses.

The Chester Soils. — The Chester soils are grayish brown in the surface soil with brownish-yellow subsoils, the ferric hydroxide being apparently in the yellow rather than in the red form of the Cecil soils. They are about as heavy bodied as the Cecil, but much less subject to erosion. The respiratory and circulatory systems are well balanced, while the digestive system of these soils is much more rugged than that in the Cecil soils. The Chester soils can stand more hard farming and are adapted to a greater range of crop conditions. These soils are dominant in that type of agriculture which is characteristic of northern Virginia, central Maryland, and southeastern Pennsylvania in which general farming is practiced with corn, wheat, both pasture and hay grasses, the feeding of cattle, the dairy interests and locally the production of canning crops, particularly sweet corn and tomatoes.

The Penn Soils.—The Penn soils have an Indian-red top soil and a subsoil of about the same color. They have generally a well-balanced respiratory and circulatory system, although the circulatory system appears to be somewhat more delicate than in some of the associated soils, as it is affected more in periods of low rainfall. The digestive system appears to be somewhat more delicate than that of the Chester, although it is decidedly stronger in the northern part in New Jersey than it is in the southern extension in northern Virginia. It is adapted to about the same crops as the Chester soils.

Soils of the River Flood Plains Province

The River Flood Plains province is developed along all the rivers and streams east of the Great Plains region. The soils have, therefore, developed under all combinations of rainfall and temperature that prevail in the eastern half of the United States. They are among the youngest soils as many of them are still being laid down by the occasional overflow of the rivers and streams. They vary naturally with the soil material occurring over the different watersheds of the streams and they also vary under the different climatic conditions under which they have matured their soil characters and they naturally vary in their crop adaptations as related to the different climatic conditions under which they occur.

FIG. 8. River Flood Plains Province.

These soils occur as first bottoms which are still subject to occasional overflow and as second or third bottoms or river terraces which have had more or less time to develop distinctive soil characters. The first-bottom soils are apt to have heterogeneous layers of sand, silt, and colloidal clay material from the periodic overflows varying with the stage and velocity of the flood-waters. During the process of development of soil characters in the second-bottom and third-bottom stages these strata largely disappear by a gradual interchange or translocation of the soil material.

The first-bottom soils are apt to have a sluggish circulatory system because of poor drainage and an inefficient respiratory system and are liable to occasional overflows with the consequent injury to crops. The second-bottom and third-bottom soils have a better circulatory system and a better balance between the circulatory and respiratory systems depending, however, upon the skeleton formation of the soil. It must be understood, however, that many of the bottom soils which are so high above the normal river stage as to have nearly completed their growth and where only the highest floods cover them may be among the important soils of the country.

Four soils have been selected as dominating the agriculture of this province, the Wabash, Huntington, Cahaba, and Miller.

The Wabash Soils. — The Wabash soils occur generally in the Mississippi River drainage system where the material transported by the rivers is mainly loessial or the finer sediments of the glacial province. They have black soils and dark gray subsoils. They occur as first bottoms and therefore are subject to occasional overflow and are generally poorly drained. The skeleton of the soil is composed mainly of silt with a high content of colloidal material. The Wabash soils are, therefore, very strong soils, require heavy farm equipment and will stand deep and thorough cultivation. Where properly drained they are peculiarly adapted to corn which is the chief crop with the hay grasses as the next most important product.

The Huntington Soils. — The Huntington soils occur along the rivers having their drainage area mainly within the Appalachian Mountain and Plateau and the Limestone Valley provinces. The skeleton is coarser than that of the Wabash but carries a considerable amount of colloidal material. The Huntington soils occur as first-bottom soils with rather good drainage. They are usually high in silt content, are mellow and easy to till. They have a brown top soil and a yellow or light-brown subsoil. When protected from overflow they are dominant alluvial soils in the agriculture of the eastern limestone regions and in those parts of the Appalachian Mountain and Plateau province where limestone has given rise to a considerable part of the soil material. The respiratory and circulatory systems are so well balanced that their good digestive system peculiarly adapts them to corn and hay grasses.

The Cahaba Soils. — The Cahaba soils are made up mainly of water-transported Coastal Plain material, with occasional admixtures of Piedmont and Appalachian material. They occur from the Potomac River southward to the Alabama River. The Cahaba soils occur as second bottoms and therefore are not subject to overflow. They have a brown surface soil and a reddish brown to red subsoil. Their respiratory and circulatory systems are fairly balanced and their digestive system adapts them particularly to cotton from Virginia southward and this is the dominant crop produced on this soil.

The Miller Soils. — The Miller soils are made up of material worked from the prairies of Texas, Oklahoma and Kansas including enough of the chocolate red material from the Permian Red Beds to impart a distinctive chocolate red color to the soils. They are first-bottom soils, but are generally well drained between periods of overflow. The Miller soils are importantly developed along the Arkansas, Red, Brazos, Cimarron, Canadian, Washita and Colorado Rivers in Texas, Oklahoma and Louisiana. The soils and subsoils are both dark chocolate red in color and are highly calcareous. These soils are peculiarly adapted to cotton, corn and alfalfa.

Soils of the Arid Southwest Region

The Arid Southwest region is predominantly an area of alluvial fans, in which the material has been moved by sheet waters and intermittent or transient streams resulting from infrequent torrential rains, together with alluvial soils occupying the present stream valleys. The soil material is mainly a mixture of sharp angular mineral fragments derived from crystalline rocks of granitic character, together with more recent lava flows of basalt, andesite and rhyolite, and from sedimentary and metamorphosed sedimentary rocks.

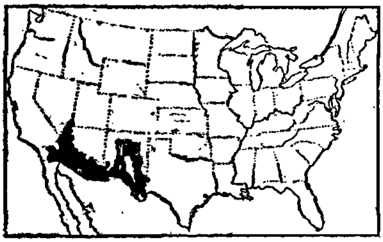


FIG. 9. Arid Southwest Region.

The soils have developed under a mean annual temperature of from 60° to 70° F. and under a mean annual rainfall of from 0 to 10 inches. The agriculture is confined exclusively to some of the old valley fillings and to the recent river alluviums.

The soils for the most part have such an exceedingly weak circulatory system that they are unable to support any of our cultivated crops without a major operation through which the circulatory system is increased and maintained by artificial irrigation. Under these conditions of extremely low rainfall the very slow movement upward of moisture from the lower depths of the earth has brought up and deposited at or near the surface in many places quantities of the most soluble soil constituents, namely, the sodium and magnesium chlorides and sulphates and in some places the carbonate and sulphate of lime. The movement of this water from the lower depths of the earth is so extremely slow, irregular and small in quantity that the lime salts, unlike the conditions on the Great Plains, are in a way subordinate to the accumulation of the more soluble salts of sodium and magnesium. Locally there are accumulations from surface wash of alkali salts from higher to lower levels.

In building and maintaining an artificial irrigation system to build up the circulatory system of a soil several things must be guarded against through the skill of the engineer and of the farmer who controls the water supply. In the first place unless the soil skeleton is sufficiently open and the colloids are moderately low there may be an obstruction in the circulatory system at some depth below the surface, so that any excessive amount of water added to a soil may overload the circulatory system and decrease the respiratory system, causing grave injury to the soil which can be relieved only by a second operation — the installation of an artificial drainage system to maintain a proper balance between the respiratory and circulatory systems in the soil for the maintenance of a proper digestive system for the crops.

Care must be exercised also before the irrigation system is started to see that there is no undue accumulation of the soluble alkali salts below the surface and to see that there is no undue amount of these alkali salts in the irrigation water, otherwise the circulatory liquid may become so concentrated with respect to these soluble salts that they injure and impede the proper digestive system of the soil and may be directly injurious to the crops themselves. Under such a rise or accumulation of alkali the only safe and efficient remedy is the introduction of an artificial drainage system with sufficient floodings to flush out the circulatory system of the soil and restore it to a normal concentration of salts.

Two soils have been selected as representing the dominant agriculture of the region, the Imperial and the Gila.

The Imperial Soils. — The Imperial soils represent the old valley filling material and are mainly lake-laid and stream delta deposits. The soil is a light reddish brown to purplish or chocolate brown. The subsoil does not differ materially in color from the soil. It is, however, compact, heavy and impervious. Under favorable conditions of irrigation the Imperial soils in the Imperial Valley of California have been highly developed and are extensively utilized for the production of cotton, cantaloupes, winter lettuce and alfalfa and for general farming.

The Gila Soils. — The Gila soils are derived from recent alluvial material along the present stream courses. The soils and subsoils are light brown frequently of pinkish or purplish tint and in this respect are similar to the Imperial soils. The subsoils are variable in texture and are underlain by or include porous, stratified sandy and gravelly material. The lower-lying areas are subject to overflow and to poor drainage and alkali but are usually capable of drainage and reclamation. Where irrigable these soils are highly valued for the production of truck crops, alfalfa, sugar beets, tree and small fruits and for general farming. They are most extensive and important in the Gila, Salt, Rio Grande and Colorado River Valleys.

Soils of the Great Basin Region

The Great Basin region is covered by material derived from a variety of rocks carried by rivers and assorted by the waves and currents of inland lakes which have receded or entirely disappeared. The surface has also subsequently been modified locally by wind-laid material and in part by outwash fan material from the tops of mountains which were left exposed as the valleys were partially filled by sediments. This soil ma-

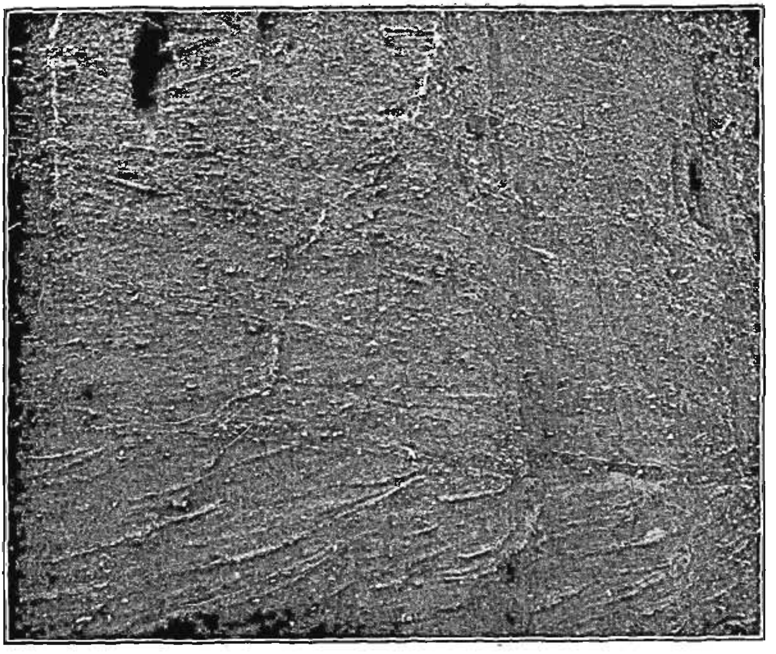


PLATE I

A page from the Book of Nature from which the age and development of life on the earth is being deciphered by scientists. This particular page shows shells preserved in rock, the kind of shells fixing the age of the material.

terial has developed its soil character under a present mean annual temperature of from 40° to 50° F. and under a mean annual rainfall of from 0 to 10 inches.

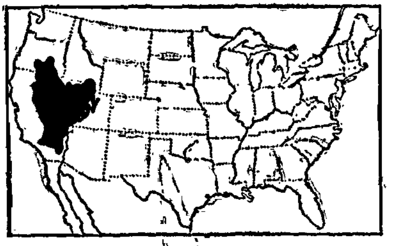


FIG. 10. Great Basin Region.

The circulatory system is everywhere very deficient and on account of limited supplies of water and the general occurrence of alkali salts in the flat lower-lying areas it is only in a few favorable localities that it has been possible to install the necessary irrigation systems to maintain a sufficient circulatory system in the soil for the production of agricultural crops.

Two soils have been selected as representative of the agricultural soils of the region, the Trenton and the Hyrum.

The Trenton Soils. — The Trenton soils are from the more recent and but slightly modified lake-laid valley filling material of mixed rock origin. They have a grayish brown to pinkish brown surface soil and pinkish gray to pinkish brown subsoil, highly calcareous. The heavier members of the series such as the silt loam and the clay loam are low-lying and portions of them have a very sluggish circulatory system. These heavier soils are used mainly for dry farming to grain and alfalfa.

The soils with coarser skeletons lying at somewhat higher elevations have a deficient circulatory system which needs to be supplemented by an artificial irrigation system although considerable areas are dry farmed. When suitably irrigated these higher soils produce fine crops of sugar beets, potatoes, grain, alfalfa, corn and onions.

The Hyrum Soils. — The Hyrum soils occupy the old lake terraces and upper marginal valley slopes. They are derived from old lakeshore and stream delta deposits which have in places been modified by accessions of alluvial fan or loessial material. The parent materials have had their source mainly in a variety of sedimentary and metamorphosed sedimentary rocks in which limestone and quartzite materials are conspicuous or predominate. The surface soils are of brown to dark brown color, frequently becoming nearly black when moist, and are underlain by lighter brown subsoils having a porous substratum of sands and rounded gravels, the materials of the subsoil, or substratum, usually being calcareous and the gravels lime coated. The soils are well drained and free from accumulations of alkali salts, but they usually have a deficient circulatory system and require irrigation. While less extensive than the adjacent low-lying lake bottom soils of the valleys, they are adapted to a wider range of crops where irrigated and are important in the production of grains, alfalfa, sugar beets, small and orchard fruits, and vegetables.

Soils of the Great Plains Region

The Great Plains region extends from Canada on the north to the Mexican border and from the Rocky Mountains eastward for a distance of 600 to 800 miles. The elevation above sea level along the western border is about 8,000 feet sloping down to an elevation of about 800 feet on the eastern side.

FIG. 11. Great Plains Region.

The soil material is a heterogeneous mixture of outwash material segregated to some extent into coarser and finer portions by river and ocean action and was at one time the bottom of a shallow ocean. The material was largely consolidated into sandstone, shale and limestone, was afterwards elevated above sea level and has since been covered to a certain extent by outwash fan material and by wind-blown deposits of sand and silt and in the northern portion by glacial material.

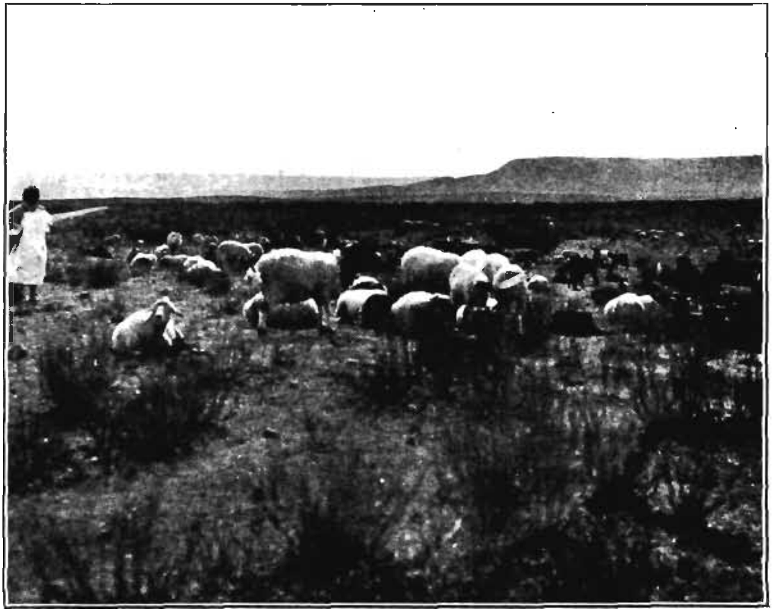


PLATE II

Nomads with their tents, flocks, and herds. From a recent photograph in Algeria. This type of life has changed little in the centuries and is antagonistic to a settled agriculture.

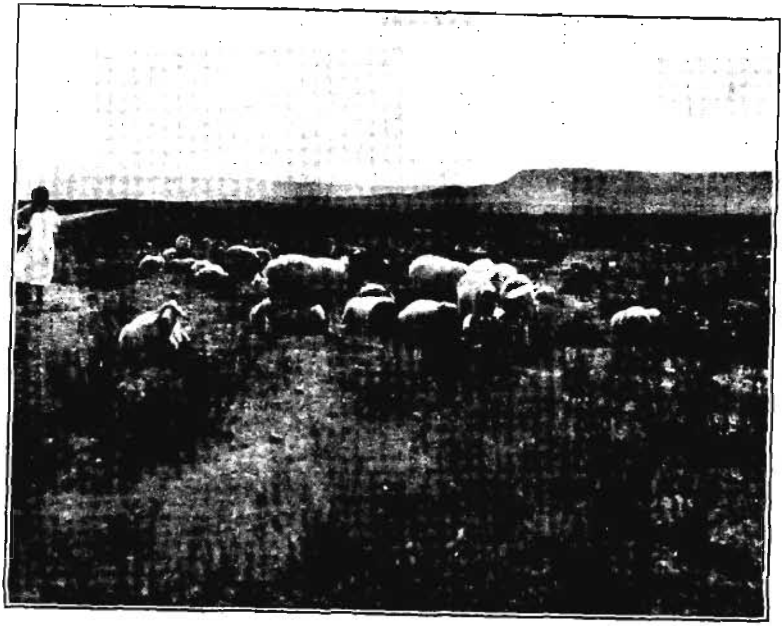


Plate II

Nomads with their tents, flocks, and herds. From a recent photograph in Algeria. This type of life has changed little in the centuries and is antagonistic to a settled agriculture.

The soils have developed west of the 100th meridian under a mean annual rainfall of from 10 to 20 inches and east of the 100th meridian under a mean annual rainfall of 20 to 30 inches. The temperature conditions vary from less than 40° F. mean annual temperature along the Canadian border to 70° F. at the southern extremity in south Texas.

Under the semi-arid conditions prevailing throughout the western part of the region with an average rainfall of from 10 to 20 inches the slow and gradual movement upward from the lower depths of the earth has brought up considerable amounts of lime in the form of the bicarbonate which has been precipitated at places and in certain soils at depths below the surface in the more insoluble form of the normal carbonate. The rainfall, although small, has been sufficient to flush the soil of the more soluble alkali salts, which are found in the more arid regions farther west, and has left generally a substratum of highly calcareous material.

Under these conditions of 10 to 20 inches of rainfall the soils have an exceedingly weak circulatory system and have to be cultivated with the utmost care to maintain a sufficient circulatory system to produce most of our farm crops, and the risks of crop production under the systems of dry-land agriculture are very great. Under these semi-arid conditions the heavier and the lighter textured soils are less safe than are the soils having a medium skeleton.

On the eastern border of the Great Plains region, generally speaking east of the 100th meridian, under a rainfall of 20 to 30 inches, the soils have a stronger circulatory system and are therefore much safer and better adapted to crops than on the western portion.

Seven soils have been selected as having a dominant influence on the agriculture of this region, the Barnes, Morton, Colby, Crawford, Oswego, Vernon and Amarillo.

The Barnes Soils. — The Barnes soils are derived from glacial till and occur in regions that have been subjected to very little erosion or leaching. The surface soils are dark brown to black.

The subsoils are yellow or gray and contain large amounts of lime. The Barnes soils have a gently rolling surface and are well drained. They have in the eastern part under a rainfall of 20 to 30 inches a fairly well balanced respiratory and circulatory system and a digestive system which can withstand a long period of continuous cropping in a single crop without serious injury. Where the rainfall is from 10 to 20 inches the circulatory system is generally weak and is adapted to spring crops of wheat and barley and to flax. The area of these soils and their associated terrace soils are nearly coextensive with the spring wheat belt of the United States.

The Morton Soils.—The Morton soils are derived from fine-grained sandstone and shale. They are undulating to rolling in topography. The surface soil is brown with a light brown to gray subsoil. The substratum is highly calcareous, the drainage is good. The circulatory system is light and has to be maintained with the greatest care to provide for spring crops. They are important spring wheat soils of the Dakotas and the eastern part of Wyoming and Montana.

The Colby Soils.—The Colby soils are derived from wind-laid (loessial) material. They have an ashy gray surface soil with a light yellow highly calcareous subsoil. They are the dominant wheat soils of western Kansas and important wheat, corn, and forage crop soils in northwestern Kansas, and southwestern Nebraska and eastern Colorado. Under the low rainfall of the region it requires the utmost care in cultivation and in cropping to maintain an adequate circulatory system in these soils.

The Crawford Soils.—The Crawford soils have been derived from limestone and limestone is frequently encountered from two to five feet below the surface. The soil itself contains only a small percentage of lime. The surface soil is dark brown to reddish brown and the subsoil a reddish brown to red. They are developed largely east of the 100th meridian where the rainfall is sufficient to give them rather a strong circulatory system. The Crawford soils are important for general farming and fruit growing in eastern Kansas, western Missouri, Oklahoma and northern Texas.

The Oswego Soils. — The Oswego soils are derived mainly from shale. The surface soil is dark gray to black with a drab to yellow subsoil. The subsoil is compact and rather impervious. They occupy level to gently rolling prairies and are less productive than the Crawford soils because of a weaker circulatory system. They are, however, important soils for general farm crops in Kansas, Missouri, and Oklahoma.

The Vernon Soils. — The Vernon soils are derived from the sandstone and shale of the Permian Red Beds. The soils are reddish brown to red and the subsoils are red. The subsoils are quite compact and contain, with the substratum, large quantities of lime and gypsum. The Vernon soils are peculiarly adapted to wheat, corn, cotton, and forage crops (particularly sorghums) and to alfalfa where the circulatory system is sufficiently strong. They form the productive red soils of Kansas, Oklahoma, and western Texas.

The Amarillo Soils. — The Amarillo soils are derived from outwash plain material consisting mainly of sandstone and shale with some granite. The soil is a chocolate brown to a reddish brown and the subsoils are brown to reddish brown. The substratum is white or pinkish white and is composed of highly calcareous material. The Amarillo soils occupy the high plateau of Kansas, Oklahoma, and Texas and are dominant in the production of kafir and small grains in the region in which they occur.

Soils of the Northwest Intermountain Region

The Northwest Intermountain region is complicated in many ways. Beneath the present soils, accumulated through a variety of agencies, are sheets or flows of basaltic rocks of comparatively recent date. There are places in which the soil material is composed in part of pumice ejected from volcanic cones or craters now extinct.

In the northern part of the region there are extensive outwash plains from glacial action and much of the present surface soils consist of materials brought in and worked over by preexisting streams and lakes. There are also large areas of coarse material drifted about by wind and of fine material which has been transported by wind over long distances.

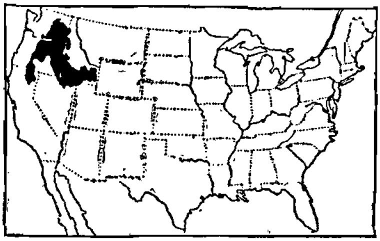


FIG. 12. Northwest Intermountain Region.

Whatever the climate of the past may have been the soils at present have matured under a mean annual temperature of from 40° to 55° F. and under an annual rainfall of from 10 to 30 inches or less.

Two soils have been selected as representing the dominant agricultural soils of the region, the Palouse and the Yakima.

The Palouse Soils. — The Palouse soils are derived from fine-textured wind-borne or loessial materials of uniform, homogeneous, unstratified character which have accumulated to the depth of many feet over the regional basaltic rock materials. The surface soils are of brown to very dark brown or nearly black color, and are underlain by compacted lighter brown subsoils grading into a substratum of yellow, or tawny yellow material. The surface is strongly rolling to hilly and deeply entrenched by stream valleys and ravines. The circulatory system is somewhat limited, but the soils are devoted upon an extensive scale to the production of both spring and winter wheat under a system of dry farming and summer fallow. These soils constitute the dominant soils of the great Palouse wheat growing country of eastern Washington, northeastern Oregon, and northern Idaho.

The Yakima Soils. — The Yakima soils are composed of river flood plain deposits mainly basaltic in character. Both the soil and subsoil are of nearly uniform color, varying from a light brown to brown. They are usually underlain by a porous sand or a gravel substratum. Naturally these soils have a weak circulatory system which needs to be reenforced by an artificial irrigation system. When the respiratory and circulatory systems are thus properly adjusted these soils can be highly developed for the production of choice apples, pears, and other tree fruits, small fruits, hops, and alfalfa.

Soils of the Pacific Coast Region

The Pacific Coast region extending from Canada to Mexico is made up of several mountain ranges mainly parallel to the Pacific Ocean, with narrow to broad valleys or basins. The mountains are made up of a great variety of rocks, largely old crystalline, metamorphic and sedimentary rocks with locally large areas of more recent eruptive rocks, so that each valley varies in the kind and mixture of soil material according to the particular area which it drains.

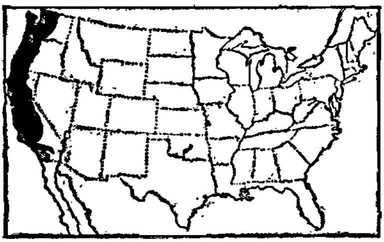


FIG. 13. Pacific Coast Region.

The climate also varies in adjacent valleys and even in the different portions of the same valley according to the height and direction of the surrounding mountain ranges and to proximity to the ocean. The rainfall varies from 100 inches in the extreme northern part on the coast to less than 10 inches in some of the interior valleys. The mean annual temperature ranges from about 45° F. in the northern part to over 70° F. in the southern part.

Five soils have been selected as illustrating the dominant agricultural soils of the region, namely the Hanford, Fresno, Placentia, San Joaquin and the Stockton.

The Hanford Soils.—The Hanford soils are composed of recent alluvial fan and river flood plain materials, which have not been weathered sensibly since deposition. They have been developed mainly from granites, gneiss and similar quartz-bearing igneous and metamorphosed igneous rocks. The soil and subsoil are brown to light brown. These soils have naturally a deficient circulatory system but when properly irrigated are widely utilized for intensively cultivated citrus and deciduous fruits, grapes, small fruits, and truck crops. The growing of alfalfa and general farming are also important.

The Fresno Soils. — The Fresno soils are derived from old alluvial fan deposits of flat to gently sloping and frequently of hummocky or irregular surface. The lighter members of the series have naturally a weak circulatory system which has to be supplemented by an artificial irrigation system. With the proper balance between the respiratory and the circulatory systems the digestive system adapts the medium and light textured types of these soils to a high state of development in the production of raisin and table grapes and also to peaches, apricots, watermelons and alfalfa.

The heavier soils of the series have a deficient circulatory system which is very difficult to restore by reason of the fineness of the soil skeleton, flat topography and occurrence of lime carbonate hardpan. They also often carry excessive amounts of alkali.

The Placentia Soils. — The Placentia soils are derived from old valley filling material from quartz-bearing igneous and metamorphosed rocks. The soil and subsoil are red to reddish brown in color, the subsoil being compact and slightly cemented. The circulatory system is weak but where supplemented by artificial irrigation systems in southern California they are the dominant orange and other citrus fruit soils of the old valley filling material.

The San Joaquin Soils. — The San Joaquin soils are derived from old valley filling material from mixed rocks. The soils and subsoils are red or brownish red. The subsoils are heavy and compact with a cemented clay-iron hardpan which restricts the movement in the circulatory system and interferes with the development of the roots of ordinary field and fruit crops. The circulatory system is weak and the obstruction due to the hardpan makes it difficult or impossible to supplement it with an irrigation system. The soils are used mainly for the production of grains under a dry farming system, though local areas are utilized under irrigation for the production of fancy table grapes and, where the hardpan has been shattered by explosives, for figs and citrus fruits.

The Stockton Soils. — The Stockton soils are formed from coastal plain and old valley filling material of mixed rock origin. The surface soil is dark gray to black, the subsoil being yellowish brown to gray and highly calcareous and with calcareous nodules and a somewhat irregular or intermittent hardpan. They occupy low flat valley plains and are heavy and compact. The subsoil carries a high percentage of colloids. Their circulatory system is sluggish and they are difficult to drain. The Stockton soils are well adapted to the growing of rice under irrigation and they are otherwise utilized mainly for the production of other grains and for general farming.

Soils of the Rocky Mountain Region

The Rocky Mountain region extends from the Canadian border to Mexico and the soils have matured under a mean annual temperature of from 40° to 65° F. and under a mean annual rainfall of from 10 to 20 inches or less. The region is one of very bold relief and rugged topography. The rough topography in itself would prevent the cultivation of a large part of the area. The portions that are adapted to cultivation consist mainly of old valley fillings and river flood plains.

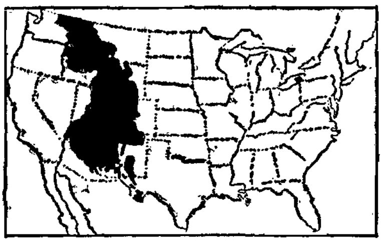


Fig. 14. Rocky Mountain Region.

Two soils have been selected as dominant in the agriculture of the region, the Mesa and the Billings.

The Mesa Soils. — The Mesa soils represent the old valley-filling material, well oxidized, of mixed rock origin. The top soil is pale pinkish red to light red, or pronounced reddish brown, while the subsoil is gray to reddish gray. The deep subsoil is highly calcareous and there is usually a substratum of gravel often partially cemented with calcareous material. The Mesa soils usually require irrigation to supplement their natural circulatory system, but where a proper balance is maintained between the respiratory and circulatory systems they are adapted to apples and peaches, alfalfa, sugar beets, and general farm crops.

The Billings Soils. — The Billings soils represent the young or slightly oxidized alluvial-fan and stream-laid material mainly of shale and sandstone derivation. The soil and subsoil are gray to drab in color. There is usually a substratum of stratified stream-laid deposits of variable and alternating texture. Both soil and subsoil are more or less calcareous. The soils are immature. In many places the circulatory system is sluggish and requires a drainage system to maintain a proper relation to the respiratory system. The Billings soils are also more subject to alkali than the Mesa soils and frequently require protection against overflow of flood waters. They are less favorable to fruit culture than the Mesa soils and are extensively utilized for the production of alfalfa, stock raising, and the production of grains, sugar beets, and vegetable crops.

Summary

The application of the modern concept of the soil to the description which has been given of a number of the important soils of the United States brings out clearly the fact that there must be for any particular crop a proper balance between the respiratory, the circulatory and the digestive systems. It suggests without going into very great detail the reason for irrigation and drainage, and of such other means which have been given to man to control within the limits of his knowledge the functional activities of the soil to produce increasing yields for the increasing population of the world.

It is obvious that in a book of this size it has been impossible to describe all or even a considerable part of the soil types found within the area of the United States. It has concerned itself mainly with the important soils agriculturally of the different parts of the continental United States. Space has not permitted the introduction of many important agricultural problems that are presented in the intractable nature of the Susquehanna clay and the Iredell soils, of the exceptionally loose and porous sandhill soils, of what are known as crawfish lands, of the difficulties encountered in the agricultural utilization of some of our pine barrens and of our peat soils, and of the infinite number of local peculiarities of soil formation and soil conditions found in all parts of the country. Such descriptions can only be found in the detailed reports of the Soil Survey.

This discussion has not undertaken to go into any detail as to the cause and existence of hardpan or of gravel layers which may have an important effect over considerable areas in many localities.

The subject is presented in this form to convey the impression that the soil is dynamic and a living thing rather than the dead, inert and wholly uninteresting material that is too often known as dirt. As has been the case with animals, for the past century we have been studying independently the physical properties of soils, the chemical composition and the bacteriology. As independent lines of studies these have been most important and will continue to be important lines of research, but the time has come with soils, as it has come with animals, to consider the soil as a whole as well as in its many details of structure and composition. There are now being established schools of preventive medicine for man and for the lower animals, and the time has come when the soil type must be considered an entity and must be developed for the good of mankind as a soil type with all the possible means at our disposal. With this modern concept of the soil as a living thing it is believed that soil investigations and soil treatment may be more intelligently carried on than has been possible with the narrow views of the past.

CHAPTER III

METHODS OF SOIL CONTROL

IN buying a horse for riding, driving, light or heavy draft work, or for any other purpose, it is customary to look the animal over carefully to judge of its adaptation to the particular kind of work for which it is intended. The things to be observed are the skeleton or the size and development of the framework, the height of the animal and its weight, the length or breadth of its several parts, the color and condition of the hair and skin, the condition of the teeth and mouth, the expression of the eyes, the length and size of the legs, the condition of the feet, and the carriage and action of the horse in repose and in motion. These things give one an idea of the functional activities and development of the animal the recognition of which is essential to its most efficient and most economical use.

In buying a farm or to get a better understanding of one's own soil, it is equally important to look it over to form an opinion as to the purpose for which it is best fitted, to discover its weaknesses and its points of merit. One should note the elevation of the land above sea level and above adjoining water courses, the general slope and contour of the surface, the condition of drainage, the color and texture of the soil as well as of the subsoil and the substratum, the occurrence of gravel, nodules or hardpan, the condition of tilth, the character of native vegetation and of weeds, and the performance of the soil with respect to the growth of crops either on one's own or on neighboring farms of the same soil type. As in the case of the animal the observation of these things gives one an idea of the functional activities and development of the soil, the recognition of which is essential to its most efficient and most economical use and treatment.

Within the limits of economic possibilities, a soil type should be developed for the crops it is best adapted to produce.

A thoroughbred racing horse with its quick and nervous disposition requires a distinctly different method of feeding, of exercising, and of other care than does a draft horse with a more phlegmatic disposition and the difference in kind of work required of it. Other animals, of course, require a different treatment from that of the horse, different kinds of foods and different kinds of exercise, and are of use to mankind according to their natures and the purpose for which they can be developed. The principal methods of animal control are through the feeding, the intelligent use of exercise, which covers the broad field of training, and the adaptation of the animal to its special field of usefulness.

The principal methods of soil control, which must be modified in accordance with the character and purpose of different soil types, are crop adaptation, crop rotation, prevention of excessive erosion by water and wind, irrigation, drainage, plowing, cultivation, manuring with green manures and with stable manure, soil amendments and commercial fertilizers.

Excessive erosion by water and wind is a superficial action on the surface of the soil which will not be further discussed here, as the principles involved in such control are largely of an engineering character. The other methods of control are concerned with the circulatory system, the respiratory system and the digestive system within the soil itself.

The functions of irrigation and drainage in controlling the circulatory and respiratory systems of the soil and indirectly affecting the digestive system have already been discussed. The other methods of soil control are used mainly as a direct control of the digestive system of the soil.

The practical importance of adapting, so far as economic conditions will permit, the soil to the crop for which it is best suited is obvious. It is most economical in time and in effort. It gives more certain results. It is the line of least resistance in which the hidden or unforeseen dangers in the soil or in the processes of nature are reduced to a minimum. There is a principle involved in this adaptation which is not often recognized. The reason that certain plants are peculiarly adapted to one soil over another which has the same skeleton and the same balanced circulatory and respiratory systems is that the digestive system in one soil is better adapted to the crop than the digestive system in the other soil. A native growth of trees, grasses or weeds provides the organic food for the soil organisms and for the biochemical and chemical activities of the soil. Under cultivation the crops that are planted likewise furnish such food to sustain the activities of the digestive agencies in the soil. If the food so furnished by the growing crop or the crop remains be not adapted to the needs of the soil organisms, the digestive system is disarranged and the growing plants will suffer. It is quite analogous to the disorders which may arise in giving improper food to an animal which can not digest it either because of the natural development of its digestive system or the temporary disarrangement of its digestive system through disease or improper exercise.

Some plants, like alfalfa, will only grow on a soil containing an excess of lime carbonate giving the soil an alkaline reaction. Other plants, like blueberries, will only succeed on a decidedly acid soil. Most of our crops do better on a soil with nearly neutral reactions. In man the food is subjected alternately to alkaline and to acid conditions, the ferments in the mouth act on the food only under alkaline conditions, those of the stomach act only under acid conditions, in the upper intestines under alkaline conditions and again under acid conditions as the food descends. So it does not seem so strange that plants may react differently in soils having an alkaline and an acid reaction.

In humid countries the subsoil is usually distinctly injurious if much of it is brought up and mixed with the surface soil, and it may require several years to overcome the injurious effects of mixing in a single operation a quantity of the subsoil with the top soil. Yet in its natural position, certain plants extend their roots into the subsoil in a perfectly normal way and with normal growth, indicating normal differences in the digestive processes of the soil and of the subsoil which is a matter that at present can not be explained.

Most soils, particularly in the humid regions, do not seem to do as well with a single crop continuously grown, as they do with a rotation of crops, just as most animals require some variation or mixtures of different feeds.

There are some plants which do not live together in association, such as corn and weeds, even if they are kept supplied with ample water. There are some plants that live well together, such as timothy and clover. There are also some crops which will not follow in succession and others that seem to do better when following a certain preceding crop.

So the crop rotation has a very important effect on the digestive system and constitutes, therefore, an important method of soil control. The best rotation for one soil type is, however, not necessarily the best rotation for other soil types.

Manuring with green manures, particularly with leguminous plants and grass sod, and with stable manure in advance of planting the crop, apart from any physical effect it may have on the soil, furnishes a generally suitable and an easily digested food for the digestive system of the soil which tends to stimulate the digestive agencies and get them in active condition for the crop that is to be planted.

Plowing is a method of exercising the soil to promote digestion. Most animals exercise daily. Some animals normally do not exercise at all for several months. Some of the lower animals have no means of locomotion, and therefore apparently do not exercise. When an animal exercises once no marked benefit can be seen, but continual recurrence of suitable exercise may build up and develop the powers of the animal and strengthen the digestive system. Exercise to be of the greatest good must be scientifically adjusted to the need and present condition of the animal. If the exercise is excessive or ill-timed it may be of distinct injury.

The soil seems to need exercise through plowing only once or twice a year, or under proper rotations it is sufficient to provide this exercise once in three or four years. There are certain virgin soils, when first adapted to crop use, and coarse sandy soils in general which do not seem to be benefited to any extent by plowing, but loams, silt loams, and clays which have been compacted by the rains if lifted up and thrown down occupy more space than in their original condition, that is, their lungs, as it were, for the time being are expanded and contain more air thus aiding in the processes of oxidation and digestion.

The act of plowing furthermore buries the refuse of the preceding crop or incorporates the green manure or stable manure through the soil. It is, therefore, an act which tends to bring food material to the digestive organisms of the soil and to improve at the same time the respiratory system, which aids somewhat in the digestive processes. Plowing also is a means of shaping the surface into hills or ridges where this is desired.

The soil grains are surrounded and held together by colloidal material which is very soft, sticky and plastic when wet and gives plasticity to a soil in proportion to the amount present and yet which acts as a cement on drying, which has the effect of making the soil hard when dry. Between the extremes of plasticity and of hardness, there comes a point in the drying out of a moist soil when the colloids are neither plastic nor hard. This represents the optimum water content of a soil or the condition in which it has neither plasticity nor hardness, and this is the condition under which plowing should be performed to break the soil up and leave it in the most loose and granular condition possible. If a clay soil is plowed when too wet the grains do not fall apart for they are held in a sticky mass. If plowed when too dry the soil is thrown over in cakes or in lumps, the clods being difficult thereafter to break down. So the act of plowing must be regulated according to the nature and condition of the soil type, otherwise the results desired may not be attained and injury may result which will require time to correct. If a soil is puddled, that is, if the grains are uniformly distributed, it may not fall apart on plowing as if it had a crumb structure, and a puddled soil may require years of preparation and treatment before the act of plowing is as effective as would be desired.

The reason for the occurrence of a plow sole in certain soils where the plowing is done at a uniform depth year after year is also quite apparent since the bottom of the plow may puddle a layer making it very impervious, just as the trowel smooths out the surface of moist concrete to make the surface of the dried concrete as smooth and as impervious as possible.

A soil having the fine-grained skeleton usually associated with a high colloidal content, as in many of our loams and clay loams, is likely to be dense and more or less intractable, and to require heavy implements and heavy teams for the hard labor of turning it over; and it requires a greater depth of plowing than do the loose, porous sands and sandy loams which have less colloids and generally less organic matter to be acted upon by oxidation processes.

The Romans used to say that if plowing is intelligently done the surface should require no cultivation before the crop is planted, but at the present time many of our fields after plowing have to be gone over with a harrow, a drag or a roller to complete the pulverization of the surface and leave it in a smooth and friable form. This part of the cultivation, therefore, is a finishing up of the plowing operation and the amount of it depends largely upon the skill and the conditions under which the plowing was done. Land so prepared, besides giving a loose seed bed for roots to develop through, also takes in the rainfall more quickly and tends to prevent erosion, except under extremely heavy rains.

Cultivation of the soil after the crop has been planted is mainly for the prevention of weeds, which, as has been stated, are antagonistic to the growing crop. Crops that are thickly seeded, like the grains and grasses, if they get started before the weeds, can usually protect themselves as they are as antagonistic to the weeds, as the weeds are to them if they get the start. Crops that are not thickly seeded, such as corn and cotton, require help through cultivation in their struggle against their enemies.

Cultivation also is a method for changing the surface of the soil to a certain extent. It is also an operation which tends to conserve moisture, which might otherwise escape directly into the atmosphere.

There are a great many soil amendments that can be used locally to improve the soil conditions, such as sand spread on a clay soil or clay spread over a sandy soil, coarse or fine organic matter of various kinds, but the principal and most widely used substance is lime, either in the form of the hydrate or the carbonate.

The function of lime in the soil is twofold; it may have a direct effect upon the physical structure of the soil, or it may have a direct chemical effect. Lime is a substance that has a very powerful effect in coagulating colloidal material. A soil colloid suspended in limewater coagulates very readily and settles to the bottom as a jelly-like material, leaving a clear layer of water above, which would be entrapped by the colloid for a long time in the absence of lime or some coagulating agency. In a soil which has a tendency to assume a puddled state the addition of lime tends to coagulate the colloids and to give the soil a more granular condition, in which state it is more easily worked and in which the respiratory and circulatory systems may be improved.

Chemically the lime has the power of combining with certain acids which may be generated in the soil as a result of digestive processes and thus to neutralize certain products of digestion as it does in the animal system. It is also a means of turning the reaction of the soil over to the alkaline side as required by certain crops, notably alfalfa. It is frequently considered advisable to apply lime where considerable organic matter is turned over to prevent the formation in the soil of free acids which may be detrimental to crops. There are certain acid conditions in the soil, namely, those formed by aluminum salts which are possibly best handled by the use of acid phosphate.

There is a wide difference of opinion as to the mode of action and the cause of the beneficial results in the use of commercial fertilizers. So important is this method of control and so much additional light is thrown upon the present concept of the soil that it is considered advisable to assign it a separate chapter and to treat it fully, although there will necessarily be some repetition of facts that have been previously used.

Summing up the matter that we have just gone over it appears that all of the important methods of soil control have to do with the control of the respiratory system, the circulatory system and the digestive system of the soil, and it is the skill with which these methods are used that makes for success or failure in the handling of the soil to obtain satisfactory results when seeds or plants of good vitality are put into the soil.

CHAPTER IV

THE RÔLE OF FERTILIZERS

Introduction

FERTILIZERS have been applied to the soil to promote the growth of crops since the earliest historic times. The same kinds of fertilizer materials were used by the ancients as we use. They were mainly waste materials from the farm and from the home or from nearby cities. They used simple methods of composting. We have modified the forms of some of the materials by chemical treatment and we have discovered sources of more concentrated materials than they were familiar with, which under our industrial conditions can be brought from all parts of the world for application to individual farms. The ancients had an empiric knowledge, gained from experience and from necessity, that certain materials were of benefit when applied to the soil but they did not understand the reasons, for it was only during the nineteenth century that knowledge was acquired of chemical elements that made the reasons of this beneficial action in any way comprehensible. They saw the beneficial effects resulting from the application of various substances to the soil as they saw the beneficial effects of plowing and cultivation, of irrigation and of drainage, of seed selection, of crop adaptation and crop rotation, without any adequate explanation, because of their limited knowledge of the nature of things or of the principles involved in the growth of the plant, in the life of the animal or in the functions of the soil.

We have acquired a vast knowledge as to the constitution of matter. We have a far greater knowledge than they had of the constitution and functions of the plant, the animal and the soil, but even we have on the whole but a vague idea of the chemical and physical forces operating in the plant cell, in the animal tissue or in the soil which brings about the vital living combinations that take place during growth. The plant, the animal and the soil, each with its peculiar vital functions, are interdependent and form a cycle in the conservation and use of energy of the sun in the production and destruction of organic matter. To understand the action of fertilizers we must understand the functions of the plant, the animal and the soil which compose this cycle of energy.

We see as yet but vaguely the function of fertilizers and this lack of definite knowledge is due to three principal causes:

First, our theory as to the effect of fertilizers was formulated and became rather firmly fixed in the first half of the nineteenth century, when the existence of chemical elements had become known, it is true, but when the soil was considered a static thing. So firmly were these ideas fixed during that period that the information gained during the latter half of the nineteenth century of bacteria and other micro-organisms and other functional properties of the soil which make it dynamic has not been taken into account. The theory was too dogmatic and inelastic to be adjusted to the modern concept of the soil.

Second, our scientific investigations of necessity developed along separate and rather independent lines, so that the knowledge we acquired of the plant was without much reference to the knowledge acquired about animals and about soils, and each of these subjects were treated in different text books without much consideration of interrelations.

Third, as before stated, our knowledge of the nature and forces that go on in living things is very limited and the chemistry of living and growing things is for the most part beyond the limits of knowledge acquired of the forces used in our chemical and physical laboratories.

We are all prone in our scientific researches, as in other walks of life, to view through microscopic eyes details that appeal to our interest or sympathies, or which appear to conform to conventional ideas and lines of precedence in thought and action

Sometimes a trip from home or an interest in a different subject or a sympathetic interest in the experience of others may broaden our views and we look upon things in a broader and a somewhat saner way. Attention to details is of the utmost importance, but if this becomes too intense and confining a respite does us good, especially if it tends to enlarge our sympathies and our viewpoint, and brings into play contrasts, imagination and definite concepts.

In writing of this modern concept of fertilizers let us keep away from the details and statistics of the text books and of the professional papers, let us not take up questions of controversy as to details, but let us view the matter in the broadest way, considering the plant, the animal and the soil. Let us appeal to the imagination as well as to reason and see if we can not present a concept that will broaden our views, increase our knowledge and bring us nearer to an understanding of the part played by fertilizers in agriculture.

As we have not yet reached a point where by any method known to science we can say positively that this or that fertilizer is the best for this or that soil or crop we want, through this discussion, to show why we can not at present make such specific statements. A clear recognition of our inabilities and limited capacities will reveal some very vital relationships which have not heretofore been clearly recognized and it is hoped will present the subject in a light which bids fair to offer before long a reasonable solution of this complicated and difficult subject. Let us read further then into the pages that follow in the hope that our imagination will be stimulated and that our knowledge of the present situation when relationships have been shown may greatly advance our capacities to understand and push forward to the ultimate solution of the problem.

The Use of Fertilizers by the Ancients

The Use of Fertilizers in the Western Hemisphere. — The use of fertilizers in the older countries of the East is fairly well known through the writings of the Greeks, the Romans and the Chinese. Our knowledge of the use of fertilizers by the aborigines of the Western Hemisphere is much more meager, because of the lack of written literature.

From recent explorations and excavations it is apparent that in some of the South American countries there was an advanced state of civilization. There have been discovered remnants of vast engineering works to control floods, to drain and irrigate lands, and to regulate the land surface in terraces up to the tops of mountains. There have been discovered monuments and carvings, temples and palaces which some observers enthusiastically believe will rival conditions in Asia Minor and Mesopotamia as revealed by explorations that have been and are now being made in those countries.

On the walls of some of these excavated ruins in South America are portrayed fields of corn, but no written accounts have come down to us of what the people did or the methods they employed — just a vague idea of their former development with utter silence as to the time in which they lived and with no description of their thoughts and of their lives in written records. The first record we have comes from the contact of the Spanish explorers with the descendants or the successors of these people and these records contribute very little of value to this particular subject.

On the North American continent the aborigines in the extreme western and southwestern part of the country are supposed to have had a stable form of life and of agriculture, but with no written records to give us an insight into their lives and occupations. Over the rest of the country when the white man first established contact, the aborigines were a nomadic people without the flocks and herds of the nomads of Arabia and of Africa. They lived essentially upon the wild things of nature through hunting, trapping, and fishing. They had no stable agriculture, but had occasionally their patches of maize, tobacco and a few other things. They had no herds of cattle or of sheep. They were children of nature, living in tents and dependent almost entirely upon what nature provided without control on their part of the supply of food or clothing.

In the report of the Commissioner of Patents for the year 1853 in the volume on agriculture, page 96, there is a very interesting account, said to have been related by Mr. Schoolcraft of the Ojibwas, of the mythological origin of maize or Indian corn, which Longfellow has used in the Song of Hiawatha in the chapter on Hiawatha's fasting. It shows the pathetic longing of their mythical leader and prophet for a change from the wild nomadic life to a settled and more stable life for his people; the same kind of longings and of aspirations that Abraham, Moses and the other leaders of Israel had to change their people from the nomadic to the settled agricultural life of a quiet and contented nation.

The chapter opens as follows:

"You shall hear how Hiawatha
Prayed and fasted in the forest,
Not for greater skill in hunting,
Not for greater craft in fishing,
Not for triumphs in the battle,
And renown among the warriors,
But for profit of the people,
For advantage of the nations."

On the first day of his fasting he wandered through the leafy woods and saw the deer, the rabbit, the squirrel, the pigeon, and the wild goose. On the second day of his fasting he saw the wild rice and the blueberry, strawberry, gooseberry and grapes. On the third day of his fasting he wandered by the lake and saw the fish, the sturgeon, perch, the pike and the herring. Each day as he came back exhausted to his wigwam he offered up this prayer; "'Master of Life' he cried despondent, 'Must our lives depend on these things?'" On the fourth day of his fasting:

"He saw a youth approaching,
Dressed in garments green and yellow,
Coming through the purple twilight,
Through the splendor of the sunset;
Plumes of green bent o'er his forehead,
And his hair was soft and golden."

This youth announced himself the friend of man, Mondamin, from the Master of Life descending. He told Hiawatha that his prayers had been answered in Heaven as he prayed not for himself;

"Not for greater skill in hunting,
Not for greater craft in fishing,
Not for triumph in the battle,
Nor renown among the warriors,
But for profit of the people,
For advantage of the Nations."

He then instructed Hiawatha to rise up from his couch and come out and wrestle with him as the sun was setting.

"Thrice they wrestled there together
In the glory of the sunset,
Till the darkness fell around them,
Till the heron, the shuh-shuh-gah,
From her haunts among the fen-lands,
Uttered her loud cry of famine,
And Mondamin paused to listen."

The youth then instructed Hiawatha that on the next day he would conquer and that he was to strip him of his gorgeous plumes, lay him in the earth, keep it soft and light above him, keep the birds and weeds away and keep the soil stirred around him. Hiawatha did as he was told, and his fasting ended. When he saw a duplicate of Mondamin start to grow above the soil and ripen in the autumn sunshine he called his people together and had the first feast of Mondamin or Indian corn.

Thus according to the legend did Hiawatha provide a staple of food and of life which depended upon and was responsive to the labors of his people.

The Patent Office report above referred to goes on to say that the first successful attempts of the English to cultivate Indian corn was on the James River in 1608 and that in 1621 the Indians Samoset and Squanto visited the Pilgrims at Plymouth and instructed them how to plant and cultivate the corn and told them that they should put a fish, an alewife, within each hill of corn when the seed was planted. From other sources we learn that the Indians applied fish or seaweed to the hills of corn, but history is very meager and this is about the limit of our knowledge of the use of fertilizers in the Western Hemisphere.

The Early Use of Fertilizers in the Eastern Hemisphere.—In the Eastern Continent we have written history of the countries bordering the Mediterranean and extending eastward through southern Asia into China and Japan. From this and from explorations and excavations we have fairly satisfactory ideas as to happenings as far back as 1000 B.C. or perhaps as far back as 10000 B.C. Outside of this intellectual zone, that is in northern and central Asia, northern and central Europe, southern Africa and Australia, we have no records back of the first contact of the Romans with the people of northern and central Europe. Because of the lack of written records our knowledge of these people before the Roman conquest is as barren as is our knowledge of the early peoples of the Western Continent.

The writings of the old Greeks, Romans and Chinese give us the greatest insight into the use of fertilizers by the ancients because they were forced by reason of the physical conditions in their countries to give more attention to each detail of agriculture than were those people located where a stable system of irrigation was relied upon as in Asia Minor, Mesopotamia, Syria and Egypt. Fertilizers and manures appear to be less necessary and less used in countries of low rainfall, with or without irrigation, than in countries of moderately high rainfall.

The ancients did not consider that fertilizers were the all-important thing in the production of larger crops, but one of the important methods of increasing crop production. They considered of first importance the selection of soils for the particular crop to be grown, or the selection of suitable crops for the soil that they possessed, in other words the modern adaptation of soils to crops. Having decided upon the crop to be grown the most important operation to them was the plowing and proper preparation of the land which they held to be of the utmost importance. The time for plowing, the frequency and depth of plowing and cultivation was dependent upon the character of the soil and the crop to be raised. Cato when asked his opinion as to the most important methods of agriculture said, "The first thing is plowing, the second thing is plowing, the third thing is manuring."

They also recognized the extreme importance of seed selection. They recognized the importance of rotation of crops, as they held that no soil could be expected to continue indefinitely the growing of a particular kind of crop without a year of fallow or, if the farm were too small to permit of this, then the growing and turning under of a leguminous crop, or a rotation of crops suitable to the land and in suitable order of rotation to keep the soil up in its productivity. They recognized the importance of drainage and of irrigation.

In addition to these methods, and only after they had been intelligently used, they considered fertilizers as an additional available method for controlling soil productivity.

Lime and marl were used to improve the physical condition of the soil and to correct what we now call acid conditions in soils. Pliny in his campaign in England obtained a great deal of information about different kinds of marl and limestone and chalk occurring in that country, and he wrote about it for the information of the Romans and told how the different kinds of marl were used on different types of soil.

The ancients used manure and gave directions for the best means of preserving and applying it to the fields. They gave, a different value to the manure from different animals, for example the ox, the horse, the sheep, and gave directions as to the kinds of soil they are each best adapted to and the crops that would respond most readily to each. They recognized the difference in manure from animals fed on pasture and those fed with grain, giving the preference to the manure from working animals fed on grain. In Greece and in China the proportion of animals on the farms was less than those maintained by the Romans and, therefore, animal manure was of least importance in those countries because of its relative scarceness. The manure of fowls and of birds, both land birds and water fowl, was used. They utilized deposits of guano and believed that the manure from the different birds had its different properties, different values, and different application for different soils and crops. They appear to have maintained large aviaries for the production of manure for their lands. The Roman farm in the early days was fixed by statute at a maximum of about 4⅓ acres per family, so that intensive methods could be used, as it was considered to be to the best interest of the state that the utmost care be given to the cultivation of the land.

Composts were used in which were incorporated the leaves of trees and the roughage from the land, besides manure, deposits from ponds, rich earth from corners and other substances of a similar nature.

The Romans made a practice of scraping from their cellar walls and dirt floors the efflorescence that we now recognize as nitrate of soda or nitrate of potash and considered this a valuable fertilizer material. It was from similar sources that in our Civil War considerable amounts of nitrate were obtained for the manufacture of gunpowder in the Southern States. The Romans also knew, and utilized for manure, a white crystalline material found in the vicinity of volcanoes which we now recognize as ammonium chloride. They were of course unfamiliar with the Chilean nitrate deposits and with the ammonium compounds that we obtain on the distillation of coal.

Bones and the flesh and hoofs of animals were used. They had not of course the methods we have to-day of fine grinding or the treatment of the bones with sulphuric acid as we have, nor did they know anything about the concentrated forms of phosphates which have been discovered and developed in the past 60 or 70 years.

The ancients used fish and the parts of fish which we call fish scrap, and wherever it was available they used seaweed for manure. They also used human excrement and kitchen waste. The Chinese carry the conservation and use of these materials to the extreme.

Very little is said in the Roman literature about the manner or time of application of manures and it is probable that their method of application was very much like our own, as the Roman practices were introduced into England during their occupation of that country. In China, however, where the population was denser and the farms were small and were of necessity under a more intensive cultivation and where the practice has extended down without break to the present time the application of fertilizer materials has been at much more frequent intervals than with the Romans or with ourselves at the present time. In other words the Chinese in their intensive system of agriculture not only get two or three crops per year from the same land according as climatic conditions permit, but they keep the soil constantly fed in order to maintain it at all times in the highest possible state of efficiency. They give the soil no rest except such as may be imposed by low temperatures, but they are constantly feeding it to keep it in active condition at all times.

The ancients thought very highly of leguminous crops turned under and even believed that the occupation of the soil by leguminous crops, even where they were harvested, was very beneficial to the land.

They used ashes and soot and on some soils in Italy they preferred to burn their manure or composting materials and apply the ash rather than to turn under the original material.

They had of course no knowledge of the concentrated forms of potash in the German and Alsatian mines which we are now using.

The Romans used the black sediments from the rivers and lakes, often composting them before their application to the soil. The Chinese made a great practice of digging out the silt from their canals and ditches for application to the soil. In our own Southern States where erosion is rapid in the clean cultivation of cotton the soil material washed from the so-called wornout and abandoned fields is carried down by the rivers and deposited as most fertile soil material in the rice lands or the islands bordering the coast. In the slow and intermittent progress of such material down the rivers, there is a marked invigoration, a slow accumulation of organic matter, a pronounced increase in bacteria and other micro-organisms and such of this material as has been well aerated when applied to cultivated soils is a source of inoculation which tends to stimulate the digestive activities of the soils of the fields upon which placed. The Chinese appear to have recognized the facts without knowing of the reasons and this practice has prevailed with them since the earliest historic times.

The Early Concept of the Plant

We know from the writings and inscriptions that have been preserved to us that the early philosophers in the zone of intellectual thought and expression, including those countries bordering the Mediterranean and extending eastward into China and Japan, and throughout historic times, have been very curious and have been very observant of conditions surrounding material life, as well as the things associated with death and the hereafter. They were also given to intense thought and debates that brought out the most exact reasoning and logic and they recognized the distinct limitations of the human mind and intellect.

Pliny gives a short but admirable description of the earth as a globe or sphere, with the size, dimensions and movements with respect to itself and with respect to its place and movement in the universe. He admits an inability to travel far beyond the land surfaces and even within the then known extensions of land, due to the difficulties and dangers in organizing and directing travel and the transportation of supplies into and through unknown countries or on the seas where they had no fixed points to guide them.

The old philosophers had a remarkable knowledge of astronomy, they were well up in mathematical sciences, they were unexcelled in logic and in clearness of expression and they were well advanced in the engineering arts of construction and of irrigation.

They were greatly hampered by a lack of knowledge of the constitution of material things and by the mysteries and mythologies that had come to them from the past and which were fostered and dwelt upon by the priestcraft in their endeavor to impress mankind with their knowledge and control of supernatural or spiritual forces. It has been difficult for all people to distinguish between the natural and the supernatural, to hold down the imagination, to distinguish between what is presented as possible facts and those things that come under observation and are within the realm of reason and are susceptible of material proof. As the imagination has a powerful effect on the mind and even on the body, it was difficult to controvert the evidences of miracles by a logical study of material facts. Their ideas as to the constitution of matter were very limited. They knew of only four metals, gold, silver, copper and iron. They knew nothing of the remaining 92 elements, the knowledge of which came to us only a little more than 100 years ago.

In their philosophy they recognized but four elements fire, earth, air and water, and up to the beginning of the last century this was the limited knowledge that the world possessed of the constitution of matter. It was impossible, therefore, for the ancients to understand the growth of plants or the reason for the beneficial effects of the manures that they applied to the soil. The life of the plant was a mystery. They knew it was influenced by temperature, rainfall, moisture conditions, cultivation, rotation and fertilization. They had the facts but not the reasons.

They were very well versed as to the functional parts of the animal and of man. Pliny discusses the parts of the body with remarkable detail. About the functions and constitution of the plant they were naturally less informed, as we are to-day, because the functional activities of the plant do not display themselves to our observation as they do in the animal.

They had an extensive knowledge of the different plants, of the different forms and properties of the plants, and of the parts of plants. They had a knowledge of the roots and the form taken in their development, the stem, the buds, the leaves, the twigs, and the fruit. They had a knowledge of the food value of the fruits, seeds and other parts of the plant. They recognized and utilized a great many of the drug plants. They appreciated the differences in the timber trees and utilized to a great extent the ornamental trees.

They understood the necessity of spacing their plants and trees. They had the art of pruning, grafting and budding. They understood the seeding, cultivation and handling of their plants and the production of crops. They had many well-known varieties of wheat, of tree fruits and of grapes.

They had an idea that the plant absorbed the juices of the soil but beyond that they could not go. They did not understand what the plant was nor what made it grow. Why should the seedling develop from the seed and why should the seedling grow into a plant, in one case a small and insignificant form, and in the other a mighty oak or cedar?

Even as late as the early part of the 16th century, A.D., when the renaissance of agriculture had just begun, Von Helmont, a great philosopher of his time, working on the ideas of the old philosophy of the four elements, took some 200 pounds of soil and grew a seedling tree for five years, when it had attained a weight of about 170 pounds. He protected it against dust and added only water. At the end of this period he found the soil had lost in weight but two ounces, which to him was negligible, and therefore he concluded that the tree had developed out of water. Water was the one thing that he had been adding constantly. The small loss in the weight of the soil satisfied him that the plant was not derived from earth. From other considerations he concluded that it was not derived from fire or air, therefore, his conclusion that it could only have been derived from water. He failed to realize that the major part of the plant, namely the carbon, came from the carbon dioxide of the air and that the loss in the weight of the soil although trifling to him was an essential part of the growing plant.

Boyle another great philosopher of his time, in 1678 accepted Von Helmont's conclusions, but on distillation of plant material having found oil and salts, he concluded that these also had been derived from water. So the matter rested until the beginning of the 19th century when our knowledge of what the plant is, how it functions, began rapidly to take shape with the remarkable series of discoveries as to the constitution of matter that began at that time.

The ancients knew nothing about the constitution or principles of growth of the plant. They knew nothing about the constitution of the fertilizer materials they used. They could not explain things when the lack of knowledge was so complete.

Discovery of Chemical Elements

We now know that the plant is composed of certain chemical elements arranged and grouped in an infinite number of combinations. In fact when we consider the colloidal membranes which envelop the plant and its position in the soil and in the atmosphere above and within the soil, it is probable that the plant contains all of the chemical elements known to us. Most of these elements are present in such minute traces as heretofore to have escaped observation. Only a few of the elements are considered essential. Those that occur to the largest extent and which together constitute practically 100 per cent of the plant are carbon, oxygen, hydrogen, nitrogen, potassium, sodium, calcium, magnesium, silicon, sulphur, phosphorus, chlorine and iron. In addition small traces of other elements have been found in the ash of plants such as lithium, iodine, bromine, aluminum, manganese, chromium, molybdenum, caesium, rubidium, van dium and others. The elements in this latter list do not appe to be essential constituents of the plant.

Carbon was known to the ancients in the form of charco and in the natural deposits of graphite and diamond. They di not recognize these, however, as the same thing in differe forms. Neither did they recognize that it was an essenti constituent of plants. We now know that the plant can n use carbon in its elemental form, but obtains most of its supp of this element from the oxide of carbon which we call carbon acid gas or carbon dioxide which is a normal constituent of t atmosphere. It was known that animals in a confined volum of air rendered the air impure and that the combustion of cha coal in a confined space rendered the air unfit to support anim life. This gas has been isolated, but Lavoisier was the first to show that this gas was an oxide of carbon and that this is the principal source of the carbon of plants.

Oxygen was discovered by Priestley in 1774. It had been previously observed that plants growing in a small volume of air in the sunlight gave off a gas the production of which was prejudicial to themselves, but was beneficial to animals. It was finally found that animals had the power of revivifying air in which plants had grown and that plants had the power of revivifying the atmosphere in which animals had been grown. Priestley's discoveries of oxygen and the identification of the gases given off by the growing parts of the plant in the sunlight as oxygen and Lavoisier's determination of the constitution of carbon dioxide given off by animals gave the first impetus to the real study of both plants and animals in their relation to each other.

Nitrogen was discovered by Rutherford in 1772 and was brought about in the following way. It had been observed that when animals breathed in a confined volume of air the air became impure from their respiration, but when the carbon dioxide produced by them had been removed by passing the air through caustic potash the residual gas did not support either life or combustion. This residual gas he determined to be nitrogen.

Hydrogen was discovered by Cavendish in 1766 and was known under the name of inflammable air, but it was not until 1781, after the discovery of oxygen by Priestley, that Cavendish proved that water was produced by the union of oxygen and hydrogen.

Sodium was discovered by Davy in 1807. The salts of sodium had been known to the ancients and the differences between several of the salts such as the nitrate, the chloride, and the sulphate were recognized by Pliny.

Potassium was discovered by Davy in the following year (1808). He also discovered the element calcium, although as limestone, mortar and concrete, some of the salts of calcium had been known to the ancients.

Magnesium was also discovered by Davy.

Silicon was discovered by Berzelius in 1810, although the silicate rocks of course had been known to the ancients for their hardness and were used for building and road making.

Sulphur had been known to the ancients from the earliest times as one of the substances thrown out by volcanoes.

Phosphorus had been known to the ancients and during the dark ages was used by alchemists to startle by its peculiar luminosity in the dark. It was established as an element by Lavoisier in 1772 and its easy preparation from bones was devised.

Chlorine gas was discovered by Scheele in 1774, but was proved to be an element by Davy in 1810.

Iron has been known from the earliest times. It was in common use by the Chaldeans and Assyrians.

These were the beginnings of the acquisition of knowledge as to the constitution of matter. Lavoisier and de Saussure entered the field with their admirable skill in quantitative methods and studies and the science of chemistry was established on a true and accurate basis. It is interesting to note that the most intensive thought on the nature of things and the proportionality of chemical changes was inspired by the vague longings to understand the nature of plants and animals and the reason for their interdependence.

In a statement of this kind it is impossible to give the details of the controversies, the wranglings, and the heartburnings that took place among the men of that period, when the Aristotelian principle of the four elements fire, earth, air and water, which had come down through the ages as a firm belief, and the phlogistic theory were finally abandoned at the beginning of the nineteenth century, and the enthusiasm and loyalty to exact facts began to take its place. Even yet a comprehensive history of this period and of that immediately following has not been written.

The time between 1780 and the present may be divided into three periods — from 1780 to about 1860 would be the first period, from 1860 to 1900 the second and from 1900 onward the third. In the first period de Saussure was establishing the fact that plants obtained their carbon mainly from the carbon dioxide of the air rather than directly from the soil. Sprengel was studying the ash constituents of plants, which he assumed to be of distinct importance. Boussingault was working on pot experiments to show which of the elements in the plants were derived from the soil, which from the air, and which were essential to the growth of plants. Schübler was working on the principles of soil physics.

In 1840 Liebig startled the world by publishing his famous volume entitled "Chemistry in its Application to Agriculture and Physiology." This started a fierce and bitter controversy among the scientists of Germany itself, of France, England, and America. His views were dogmatic and were too narrow to meet the conditions of life and his opponents bitterly assailed him, hurling at him fact after fact that his theory did not cover. They called attention to the influence of climate, to the influence of the physical properties of soils, to the variations in the ash content of the same plant grown on different soils, to the utter lack of correlation between the chemical composition of plants and of soils, and to the permanency of the agriculture of some of the older countries of the world. They annihilated his theory that the plant obtained most of its nitrogen directly from the atmosphere.

In answer to the criticism that there was no obvious relation between the composition of the ash of plants and the analysis of the soil and that the ash of plants represented an insignificant portion of the chemical elements present in the soil he modified his views to the extent of admitting that only a portion of the chemical elements in the soil were in a form to be available to plants. This started another uproar and he was challenged as to a method that could be devised for determining what plant constituents in the soil were available when it was known that the total yield of crops was affected by climatic and other conditions. How could he maintain that the yield of crops was determined by the amount of available plant food material in the soil when it was known that when conditions of moisture, of temperature, were unfavorable to plants they did not grow in spite of the available plant food in the soil. Nevertheless Liebig went ahead and patented a commercial fertilizer, based upon the chemical composition of the natural guanos but made up of prepared salts, which he offered as a complete and satisfactory fertilizer for all crops and for all soils. The use of this patented fertilizer failed to meet his expectations and it was abandoned.

In the meantime in 1844 Sir John Lawes, a manufacturer and dealer in commercial fertilizers, established his famous plot experiments at Rothamsted, England, to settle the question of the efficiency of various compounds in increasing the growth of crops. These experiments were begun at a period when the soil was considered a static thing, when the amount of available plant food was considered the controlling factor in plant growth, when investigators overlooked the significance of the teachings of the Romans that cultivation was of the first importance, that cultivation must be adapted to the different types of soil and to the different crops; that a form of cultivation adapted to one soil or to one crop would not give the same results when applied to soils of a different character or to different kinds of crops. They forgot the teachings of the Romans as to the importance of crop rotations, the importance of the leguminous crops, the adaptation of soils to crops. Even our present fertilizer plot experiments root back to this period when the soil was considered static and where the main controlling factor in crop production was the amount of available plant food in soils or that added in fertilizers.

The second period from about 1860 to 1900 was concerned with bacteria and the other micro-organisms of the soil, which turn of thought resulted from Pasteur's discovery of the nature and cause of fermentation. It was found then that the formation of humus was a result of these micro-organisms. It was found that some of these micro-organisms were able to fix the nitrogen of the air into forms available to crops. It was found that the decay of organic matter in the soil was due to these micro-organisms and that the growth of particular crops, as well as the application of certain fertilizers, affected in different ways the relative growth of the different micro-organisms. It was found that the product of some of these micro-organisms were beneficial, of others the reverse of beneficial to the growing crop and that many of the facts known to the Romans, such as the influence of leguminous crops, the rotation of crops, the cultivation of the soil, the moisture content and the temperature, had an effect upon the growth and activities of these micro-organisms.

The laws of physical chemistry were then applied both to the soil and to the constituents of fertilizers and it finally dawned upon the minds of the scientists of the world that the soil is not a static thing, but is dynamic.

The third period from 1900 to the present time has developed this idea of the soil being dynamic and we see the soil now as a living thing with functional activities that are quite analogous to the functional activities of the animal, as has been explained in a previous chapter.

Modern Knowledge of the Functions of the Plant

The estimated average composition of the vegetation of the earth expressed in pounds per 1,000 pounds of dry matter is given in the table on the following page. This does not represent the composition of any particular plant, for plants vary greatly in their content of mineral elements, of the atmospheric elements, according to seasons and soils, and they vary greatly in the constituents found in the roots and tubers, in different parts of the stem or trunk, in the branches, leaves and fruit or seeds. It is not a weighted average of all plants because that would be impossible to determine. It is a theoretical composition, a broad, generalized composition, which is better adapted to our present discussion than if we attempted to give the composition of particular plants because we would be led into endless confusion in selecting one or more plants and in considering the differences between the different parts of plants.

The table following is intended first to show in the most striking manner possible that the object of the plant is to produce organic matter composed of carbon, oxygen, hydrogen and nitrogen and that incidentally it requires a small amount of mineral elements to accomplish its purpose. Very seldom is a determination made of the carbon, oxygen and hydrogen in plants as a whole because of the enormous number of compounds they may form in their different proportions of combining. It would serve no purpose and would be meaningless in any study of the composition or functions of the plant. The amount of nitrogen is usually determined in all plants or parts of plants because it has a specific meaning in the feeding value and in the fertilizer value of the plant or its parts. The analyses usually made of plants and parts of plants are to determine the amount of protein, carbohydrates (including fiber) and fat and then a determination of the total ash constituents and if necessary the composition of this ash.

Estimated Composition of the Vegetation of the Earth Expressed in Pounds per 1,000 Pounds of Dry Matter

Carbon (C)	443.0	950 pounds of elements derived from the air manufactured into	Protein 100 pounds; Carbohydrates 820 pounds; Fat 30 pounds
Oxygen (O)	429.0		
Hydrogen (H)	61.8		
Nitrogen (N)	16.2		
Potassium (K)	16.8	50 pounds of elements derived from soil minerals which assist in the manufacture of the above classes of organic matter	Mineral Matter 50 pounds
Sodium (Na)	4.3		
Calcium (Ca)	6.2		
Magnesium (Mg)	3.8		
Silicon (Si)	7.0		
Sulphur (S)	3.7		
Phosphorus (P)	5.6		
Chlorine (Cl)	2.2		
Iron (Fe)	0.4		
	1,000.0		1,000 pounds

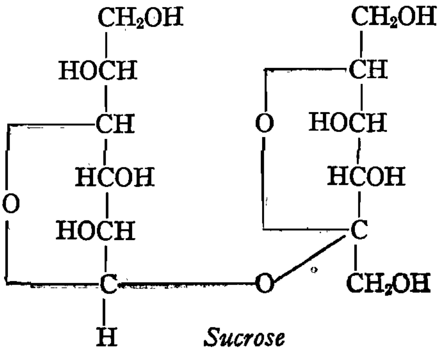
The protein bodies are very similar in their ultimate composition of carbon, oxygen, hydrogen and nitrogen and the amount of protein is usually determined by multiplying the nitrogen content by the factor 6.25. There are known to be, however, a great variety of protein substances having very different properties depending upon the way these elementary atoms are built up. In the same way the carbohydrates (including fiber), the fats, and oils are each very similar in their average content of these four elements but differ greatly in their properties according to the manner in which these elements combine and are built up into complex organic molecules. When we are able to isolate a pure protein, or a carbohydrate, or a fat, which has a definite crystalline form, a constant melting point, or in the case of a liquid, a constant boiling point, we then resort to an elementary analysis because slight variations in the amount of these elements present may assist in their identification and classification.

Plants are grown or are used for a great variety of purposes. The different forest trees, such as the oak, the ash, the fir, the pine, are utilized for timber, for lumber, for paper making, and a variety of other mechanical purposes. Some produce nuts as a valuable food product, such as the chestnut, the walnut, the pecan. Some plants are used chiefly for their fiber such as cotton, hemp, sisal, and flax. Some are used in their entirety for food purposes for animals or for man such as grass, clover, cabbage, lettuce, celery. Some are used in part for food purposes, the seed of grain, the fruit of certain trees. Some plants are used for their juices, the sugar maple, the sugar beet, the sugar cane, the pine for its resin and turpentine, the rubber tree for its sap; among the seeds, linseed, cottonseed for their oil. Some plants are used for decorative purposes, for their form, their color and their scent. We have a great variety of drug plants from which valuable drugs are extracted.

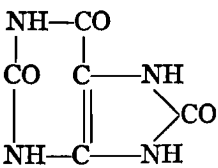
This infinite array of plants of different forms and shapes, of different capacities to supply human needs and desires are composed principally of four elements carbon, oxygen, hydrogen, and nitrogen in much the proportion as given in the table but with an infinite variety of combinations and of forms.

With 26 letters in what we call the alphabet, a few marks of punctuation and a few numerals mankind expresses the whole range of thought. Words and phrases are built up to express feelings of the utmost joy or of the deepest despair, words of comfort or of condemnation, words that express the will of the people as written into the laws of the land, the needs and aspirations of the individual, the religions and philosophies of life, the events of the day, the histories of the past, — in short the entire intellectual world in which we live. This is made possible by the combinations and building up of words and phrases out of what seems an insignificant number of letters. Each word has its own significant meaning and effect, as "Yes" or "No," "Come" or "Go." The organic material of plants is made up, of equally few elements with an infinite number of combinations which have each their different meanings and their different properties as the words and phrases of our literature. The same letters arranged in different order in words and sentences may convey entirely different thoughts; the same chemical elements arranged in different orders and different combinations produce organic materials of entirely different properties. Scientists are to-day attempting to read the various combinations of these elements in the different organic substances derived from or contained in the plant or animal, as we endeavor to study and elucidate a code message.

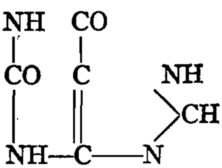
The following chemical formulae will tend to make this clear.

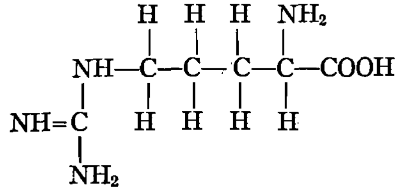


Sucrose



Uric Acid





Arginine

We have here the letters representing carbon, hydrogen, oxygen and nitrogen. Each group of letters would constitute a word while the words are arranged in sentences. The formula for sucrose means sucrose to the chemist and the words contained therein give him a complete understanding of the constitution of sucrose. It conveys to him the same meaning that the sentence descriptive of a building or of a machine conveys to the builder or to the engineer. In fact it would take a number of sentences to describe the composition and constitution of sucrose in what we call the English language. This is the language of the scientist in describing organic substances and illustrates very forcibly what we mean by the plant building up very complex substances out of a few elements, as the expression of a law or ideas in a poem is conveyed by arranging a few letters to form different words and different sentences.

When a lighted match is applied to shavings under a pile of organic matter properly conditioned and arranged so as to maintain a free circulation of air and with only a moderate amount a moisture it is like introducing a bull into a china shop, — everything is torn asunder and the fire gains energy as it oxidizes and breaks down the complex organic bodies with the release of the energy from the sunlight stored up originally by the leaf. This energy manifests itself to us in the form of heat and flame and the plant material is resolved directly and quickly into the simple components of carbon dioxide, water and nitrogen which are thrown back into the air for plants to use over again and to the ash constituents composed of the mineral elements in the plant which are left on the ground.

The soil digestive system accomplishes the same ultimate purpose but with only a moderate rise in temperature as the action is infinitely slower. Furthermore the action of the digestive system in its final analysis proceeds in an orderly way according to the rules of the game which each player is compelled to follow according to his ability and his place.

A single bacterium, with the enzyme that it may form and in the presence of water and of oxygen and at suitable temperatures in the dark, completes its life history and its activities in but a brief time. During this brief period it gets its energy for growth if it has presented to it organic bodies that it can digest and break down in part at least into carbon dioxide and water but during its growth and with the energy so provided it must build up the compounds needed for its own growth and development. That portion of organic matter that the body contains at the time of death must be digested by agencies which follow after to clean up its own debris. Under the rules of the game what does not completely digest to carbon dioxide and water must be left in a well-balanced state to form a definite chemical compound. Digestion may take out a single letter or a group of letters forming a word in the formulae, just shown but it must leave the unused letters and words in a form which spells another compound. If the organization can not do this it can not digest that particular substance. These changes are assisted by the mineral elements.

In the case of uric acid in the formulae given, it is the function of certain organisms to split it up into ammonia, carbon dioxide and water. This is as far as they can go. Other organisms can oxidize the ammonia and change it into nitrites. Still a third and different set of organisms can oxidize these nitrites into nitrates in which form they are supposed to be directly taken up by growing plants. So the operation is dependent upon the orderly action of different classes of digestive organisms.

In the case of dextrose we may have the sugar broken up by one set of organisms into alcohol, by other sets of organisms oxidized into different acids such as acetic, formic, propionic and butyric. Different sugars can only be attacked by different organisms and the ability of bacteria to digest the different sugars is a common method for identifying species in certain groups of bacteria. Specific kinds of bacteria are required to work on cellulose and on woody fiber, other groups to work on the sulphur compounds. It is apparent therefore that in the digestive system of the soil there are an infinite number of jobs to be attended to and each job in its different parts requires often specific agencies for its accomplishment. It is to us a heterogeneous operation but it must have a most orderly course to accomplish and complete the final work and these organisms must work in relays to accomplish the final end, one organism going so far, another taking up its products or what is left from its energies and carrying it further and further through various stages until the whole original mass of material has been finally digested. Always, however, these digestive agencies must be nourished and fed in order that they may have the energy to proceed to carry out their preordained function.

We must not forget that in this life in the soil there are at all times contending forces, parasites, so to speak, that attack the normal forces of digestion — the same struggle for existence that we see in the life around us, the same dangers from enemy invasion, the same vagaries of climatic conditions, the uncertainties of food supply, the kind of crops grown, the conditions of cultivation, the lack of intelligent care, all these tend to make existence and efficient work in the depths of the soil as uncertain as they are uncertain in our own lives.

Up to the early part of the nineteenth century it was believed that organic compounds were only formed in a living body through the agency of what was considered the vital living principle. In 1828, however, Wöhler artificially prepared urea, which up to that time had been supposed to be a product peculiar to animal life. A few years ago there was celebrated in Germany the discovery of the fifty thousandth organic compound that had been synthetically prepared. Since that time, of course, many thousands more have been prepared.

Returning to our table illustrating the average composition of plants, the great lesson it teaches is that it is the main function of the plant to produce organic matter. Nine hundred and fifty pounds out of every thousand pounds of dry matter contained in the plant is organic. Fifty pounds represent the mineral elements obtained from the soil.

The carbon is derived almost exclusively from the small amount of carbon dioxide in the air and is taken in through the leaves and the other green parts of the plants. The hydrogen is derived from water which precipitates from the air, enters the soil and is taken up through the roots of the plant. The oxygen is derived from the carbon dioxide of the air and the water that enters the roots, the excess of oxygen from these sources being eliminated and thrown off into the air through the green and growing parts of the plant while the plant is exposed to the direct or reflected light of the sun. The nitrogen is taken up through the roots from the soil. As the rocks from which the mineral matter of the soil is derived contain little or no nitrogen it is probable that practically all of the nitrogen supply in the soil has been originally fixed through some process from the gaseous nitrogen of the air.

All of the mineral elements are taken up by the plant through the roots.

One of the peculiar things that develops in comparing the ash constituents of plants with the chemical elements of the soil is that the main constituents of the soil are silicon, aluminum, and iron, which are very subordinate constituents of the ash of plants and of which only traces of iron are supposed to be of any importance in the constitution or functional activities of the plant. The reason for this becomes obvious only through the most recent development of soil investigations. The abundant amounts of silicon, aluminum and iron which go into solution in the soil when the minerals disintegrate go into the form of colloidal solution. Colloids can not pass through colloidal membranes such as the plant is surrounded with and this physical state of matter evidently protects the plants from an inrush of such an abundance of useless material.

The plant unlike the animal or the soil has not a pronounced closed circulatory system. It has a transpiration system in which the water with much that is in true solution therein is taken up from the soil and what is not needed in the plant itself is thrown off into the atmosphere, mainly through its actively growing surface. From 300 to 600 pounds of water are thus transpired by the plant for every pound of dry organic matter formed within the plant. There may be a downward movement of water in certain layers of cells but the pronounced closed circulatory system of the animal does not appear to be represented in the plant.

This vast amount of water transpired by the plant is apparently leakage analogous to the leakage of water through the skin of the animal and to the leakage of water from the surface of the soil into the atmosphere. It is not essential to the growth of the plant as plants grow readily during a very moist season when transpiration is low, and they grow as readily in a Wardian case where there is little or no transpiration on account of the complete saturation of the atmosphere as they do when the atmosphere is moderately dry and transpiration is large.

Plants decompose the carbon dioxide and the water to combine them into organic compounds only in the leaves and green parts of the plant where chlorophyl is present and only in the sunlight or the diffused light of the sun, from which they obtain the energy required for building up these complex organic materials.

Under only these conditions and in these places are they able to build up organic compounds from the original elementary atoms contained in carbon dioxide and in water and this only when they are exposed directly or indirectly to sunlight from which they derive their energy. The building up of complex organic compounds out of simple elements like the construction of a house through the piling up of bricks and mortar, the elevation and placement of steel girders, requires energy to be expended. The energy used in the construction of a building comes from man power, horse power, fuel and water power which all derive their energy directly or indirectly from the sunlight. The energy required in the building up of complex organic matter in the green cells of the leaf comes from the energy of the light rays of the sun, which the plant alone is able to utilize directly in some mysterious way. According to the laws of the conservation of energy when a complex structure falls down or is gradually unbuilt there is a release of energy equal to that required to build it up and this released energy manifests itself and can be utilized in several ways.

In the green cells of the leaf, therefore, the plant is able, in the sunlight and at moderate temperatures, to utilize the energy of the sunlight in building up out of the elements of carbon dioxide and of water the complex molecules of organic material which we class as carbohydrate and fat bodies. With a supply of nitrogen it is also able to build up the protein bodies. A marvelous provision of nature this — the beginning of a cycle of energy and of life which permits of the growth of the plant, which provides the energy for the growth and activities of the animal and which, as we shall see, provides for the active life within the soil from which new plants develop.

In the sunlight the green cells of the leaf combine the elements of carbon dioxide and of water to build up these complex organic bodies, but only in the sunlight or in the diffused light of the sun. When the night comes, when the sunlight is withdrawn, the plant loses this power, as the source of the energy has been withdrawn. In the darkness of night the plant may continue to grow, but only with the expenditure of energy which it stored up in the daylight. In the night time growth is accomplished by the breaking down of some of the organic material built up in the sunlight and in the night time therefore the plant gives off carbon dioxide exactly as the animal does both in the sunlight and in the night time.

While the original source of the energy required for the growth of the plant is in the green cells of the leaf, the continuous growth of the leaf during the night as well as the development in other parts of the plant, noticeably in the case of the maturing of the fruit and in the growth of the roots in the dark recesses of the soil, may come largely from the decomposition of organic matter passed down through them from the leaves. The roots of the plant therefore may give off carbon dioxide at all times as the animal does and, like the animal, require sufficient oxygen for the slow oxidation or combustion of the material out of which their energy is derived.

This is important to remember for we shall see when we come to take up the soil that the microscopic plants, which we call bacteria, which are incapable of forming the green chlorophyl and which work in the perpetual darkness of the soil, and acquire their energy of life and of activity from the organic matter that was formed originally in the green cells of the leaf of the growing plant, give off carbon dioxide as the animal does and require oxygen for the fulfillment of their life processes. The higher forms of plants live principally on carbon dioxide and water. These lower forms of plants live principally on and derive their energy from the breaking down of organic bodies originally built up in the leaves of growing plants.

The table shows us that of 1,000 pounds of dry matter formed by the plant, 950 pounds are organic matter and 50 pounds are mineral matter. The largest proportion of this mineral matter is potassium, 16.8 pounds; while the smallest amount of any one mineral element as given in the table is iron with four-tenths (.4) of a pound. Very little is definitely known about the function of these mineral elements in the growth of plants and much of what we think we know is still in controversy. What little is known may be briefly sketched.

Potassium does not appear to be combined in any living organic compounds. It seems to be used as a buffer and to function as a catalyst assisting in reactions in which it has no component part. The plant seems to be unable to combine the carbon, hydrogen, and oxygen into carbohydrate products, except in the presence of potassium salts, yet potassium has no part in the constitution of the carbohydrates thus formed. Starch does not form in the leaf where potassium is not present, nor does the insoluble starch change to the soluble sugar for diffusion throughout the plant, nor is the sugar reconverted into starch at such points in the plant as starch usually accumulates, when potassium is absent. Potassium does not form a constituent part of either starch or sugar. This is one of the mysteries of nature which the scientist has not been able to solve. Potassium also seems to have some important effect on the formation of protoplasm by the plant and yet potassium is not recognized as a constituent of protoplasm. Potassium and calcium do combine directly with the organic acids, particularly with such acids as oxalic, malic, tartaric and citric, which are formed in certain parts of the plant and which do not continue to be formed by plants unless a suitable buffer or base is present to protect the cell from injury through the accumulation of its own acid products. Crystals of potassium oxalate, potassium malate, potassium tartrate, and potassium citrate may often be seen on the surface of leaves or fruits.

Calcium appears to function in the formation of cell tissue or of cellulose in a way that is not clearly understood. It is probable that it aids in the conversion of starch or sugar into cellulose or woody fiber.

Chlorine appears to have a function in the transfer of starch from the leaves to the fruit and in the conversion of starch to soluble forms in which it may be moved through the plant. The necessity of chlorine in the functional activities of the plant is questioned, however, by many.

Phosphorus appears to be used in the transfer of material from the leaves to the other parts of the plant and together with potassium seems to take some part in the ready transference of albuminoids. Phosphorus is used to a small extent as an essential constituent of some of the growing organic compounds, especially some of the proteins such as nuclein and lecithin.

Magnesium is an essential constituent closely associated with the production of chlorophyl in the green cells.

Sulphur is an essential constituent of some of the albuminoids and of the sulphurized oils, such as those found in the onion, mustard, horseradish and turnip.

Iron appears to be necessary in very small amounts in the formation of chlorophyl in the green parts of plants, but nothing is known as to the way it acts.

So far as known silicon does not appear to be essential to the growing plant, although it is generally believed that it gives strength to the stems of grain crops.

Very little is known about the influence of sodium, although it appears to be able to replace potassium to some extent. The weight of opinion seems to be that it is not essential to the growth of plants.

Practically nothing is known as to whether the other elements found in plants have any influence on their growth or whether they are purely accidental.

The mineral elements appear to be held very loosely in the plant, as when the fresh or even the dried plant is ground up and extracted by water a large proportion of the mineral elements are extracted in a soluble form.

The Germination of Seeds

Nature appears to have made an elaborate provision for the perpetuation of plants through seeds a consideration of which, as we see it, will throw additional light upon the office of the mineral elements in the growth of plants and in relation to the office of the mineral elements in the soil.

On the maturing of the plant relatively large amounts of proteins and fats or carbohydrates are stored in the seeds and with them relatively large quantities of potassium, phosphorus, calcium, and magnesium are placed in the seed, particularly within and adjacent to the germ. The seed when matured separates from the plant and it must obtain all of the energy in the early stages of its development and growth into a seedling plant from the energy stored up in its own tissues.

When the seed is placed in the soil it first takes up a large amount of water equal to 50 or 100 per cent of its original weight. As the germ begins to grow it derives its energy from the breaking down of the organic matter stored there and the unbuilding or breaking down of these complex organic bodies is made possible through the agency of the mineral elements, as they assisted in the building up of these organic compounds in the plant. A relatively large amount of mineral elements is rushed up to the point of growth of the germ and outside of the germ to take care of the building that is going on in the growing part at the expense of the starch, sugar, albuminoids and fat originally stored up in the seed. They apparently play an extremely active part both within and outside the germ until the root is developed into contact with the soil and the stem has emerged and thrown out the first set of green leaves when the plant is able to function for itself, to gather mineral elements from the soil to help in the active growth taking place in the leaves in the sunlight.

One can readily see from this the reason why we should give the utmost care to the preparation of the seed bed and why manures and fertilizers are supposed to be of the utmost importance in this early stage in the growth of the plant and until it establishes sufficient contact with the soil to permit in full its normal functional activities. Well-developed trees, either fruit trees or forest trees, with their enormous root systems, their large and intimate contact with the soil respond but little to applications of commercial fertilizers.

Let us follow the seedling from the point where the roots have made contact with the soil and where the leaves have made contact with the free air and with the sunlight. If the seed has fallen on good ground, for example, on a highly cultivated garden soil rich in organic matter and if the season is favorable the seedling will develop in a most luxuriant way.

If the seed has fallen on poor ground, on an eroded hillside on a raw clay subsoil, regardless of the season or the kind of cultivation the plant will not develop to meet our needs. What difference does it make to the seedling plant whether it falls on a good or on a poor soil? The one has a well-developed and an active digestive system, the other lacking organic food for the activities of the micro-organisms is destitute of an efficient digestive system. Why should the character of the digestive system of the soil affect the growth of crops?

To answer this we may go back to the experiments made by scientists in the early part of the 19th century, where they found that plants would grow in artificial soils made up of quartz sand and mineral elements, where they would grow in artificial nutrient solutions, and where they would grow in ordinary well water. It was found by these early investigators that if the well water was frequently changed by draining it off completely and replacing it with fresh well water every few days crops would grow and yield as much as they would yield on rich garden soils and would often yield more than on ordinary field soils. If, however, they failed to replenish the cultural solutions and permitted the plant to grow continuously in the same solution, spores of bacteria and of molds would enter from the atmosphere. They would attack the organic matter thrown off by the growing roots and in a short time the solution would become a fetid mass of decaying organic matter in which the plant itself would finally be involved and succumb. The same results may be expected to occur in artificial cultural solutions unless they are systematically changed. They are not likely to occur in a sand culture, where there is a freer circulation of gases and where the roots are fixed in place and the growing tip of the root is constantly extending into new material.

It seems evident, therefore, that the seedling plant as it begins to depend upon the soil requires a certain digestive system in the soil to keep the soil in a healthy condition for its continued growth. If the soil has no adequate digestive system, if the micro-organisms have not been properly fed, if they have not the energy and the vigor to look after the needs of the growing plant it will not develop in a normal way.

With such an unproductive soil as we have used in the above illustration from an eroded slope, a rich garden soil can usually be prepared, if the texture and drainage conditions are suitable, by spreading a little well-fermented stable manure on the surface and turning it under an inch or two in depth. After two or three weeks have passed more of the manure is spread over the surface and is spaded in a couple of inches deeper than the first application. Then after a little time has passed an additional application of manure is turned under still deeper and so in the course of time by introducing the micro-organisms and the food to give them their necessary energy for growth the once infertile soil can be made into a productive garden spot with a fully developed digestive system that can take care of the needs of such plants as are adapted to that type of soil.

The Rôle of the Animal

Unlike the plant the animal is unable to avail itself of the direct energy of the sunlight and is entirely dependent upon the energy of the sunlight stored up through the leaf of the plant in the organic bodies that the plant has provided. It takes into its system the organic materials that the plant has built up and proceeds to unbuild them or break them down into the simple materials of carbon dioxide and water and into simple nitrogen products such as urea. In breaking them down into simpler compounds an amount of energy is released equivalent to the amount of energy stored up by the plant from the sunshine. The animal does this through the agency of digestion and oxidation. Part of this energy appears as the body heat, part of it appears as muscular energy. Part of it is consumed in the building up of new and perhaps more complex organic bodies than appear in the plant. The animal may use organic bodies derived from the plant direct or it may change them in the building up of different products required for its different functional activities, but the energy required in doing this is derived from the material of the plant which is changed to lower and simpler forms finally reducing part of them to the simple forms of carbon dioxide and water.

In the changes that go in the animal metabolism either in building up higher compounds or in changing the constituents of the plant into constituents of the body or in the breaking down of the compounds, the mineral elements appear to be necessary and to perform functions similar to those they carry on in the plant. One striking difference between the metabolism of the plant and of the animal with regard to the part played by the mineral elements is that in the plant potassium has a large rôle while sodium seems to be an unnecessary constituent. In the animal, on the contrary, sodium in the form of sodium chloride has a very commanding and important place.

Most of the mineral elements, with the exception of sodium appear to be supplied by the plant in sufficient quantity for the functional activities of the animal. Occasionally, however, calcium, potassium, magnesium, iron, phosphorus, arsenic, iodine and other of the mineral elements are given directly to the animal as an aid in its metabolism.

The carbon dioxide and the water transpired by animals may be used by the plant to elaborate in its green leaves and in the sunlight organic bodies to be again used for the support of animal bodies. This is a two-cycle system in which organic material is built up by the plant, destroyed by the animal, again built up by the plant, and again utilized by the animal. But this system is incomplete, for the abundance of vegetation provided by the earth is far greater than the animals can consume and much of the vegetation that the earth produces can not be digested by the animal and is needed for other purposes such as for clothing and building material.

The Rôle of the Soil

The soil plays a two-fold part in the economy of nature. It affords standing room for the plant from which it may develop often to considerable distances above the earth where the leaves can gather carbon dioxide and obtain energy from the sun's rays. It holds the plant against ordinary wind storms. It offers a reservoir for water which falls upon it in the form of rain and supplies the plant with water through its roots. It helps to build up the plant, assisting in the elaboration of organic matter within the plant through the agency of certain mineral elements which it supplies as needed. On the other hand it tears down all of the organic matter given off by the plants during growth and tears down the organic matter that is not fully digested by the animal or that falls on the soil when the plant dies and is not otherwise disposed of.

All waste organic material that falls on the soil from the tender leaf or the delicate flower petals to the mightiest trees is consumed by the soil through a digestive system of a greater magnitude and more efficient for the purpose than the digestive system of the animal. Finally all plant and animal refuse is resolved again into the simple forms of carbon dioxide, water and some mineral form of nitrogen to complete the cycle of energy of the plant, the animal, the soil, and the plant, the animal and the soil again.

There are many stages in the digestion or breaking down of this organic matter in the soil, as there are in the breaking down of similar material by the animal. The micro-organisms of the soil, working in impenetrable darkness, without the power of forming the green chlorophyl of the leaves, are dependent, as the animal is for all its energy, on the organic material built up by the higher order of plants and returned directly or through the animal system to the soil.

In this digestion and breaking down of the organic matter in the soil the mineral elements are essential. They play the same part in the unbuilding of these highly organized bodies as they played in the building up in the plant and in the digestion and other living processes in the animal. They require oxygen for their digestive activities as the animal does. In combining the elements of carbon dioxide and water in the green leaves of the plant there is an excess of oxygen given off during the daylight.

In breaking down the organic bodies formed into the simple forms of carbon dioxide and water which both the animal and the soil accomplish an equivalent amount of oxygen to that liberated by the plant must be used by the animal and the soil to accomplish their final end. It has been shown that some part of the destruction of the organic bodies built up by the plant occurs in the plant itself to provide energy for its own growth when the source of solar energy is withdrawn or in parts of the plant remote from the leaves.

This is the complete and perfect cycle of the energy of life and of organic matter as we now see it. There are many different steps in it. There are many variations. There are many halts and hesitations. There is much time consumed. There is much friction between controlling forces. There is much apparent waste and inefficiency in details but the cycle as a whole and in the last analysis is complete and immutable.

In the pauses and in the conflicts between opposing forces comes the opportunity of man, even with his limited knowledge, even with his small and almost futile powers, to do what he can to direct the various stages in this cycle of energy. He has a certain control through knowledge and investigation of the development and growth of the plant. He has a certain power over the growth and development of the animal. He has a certain power to control the functional activities of the soil. It is his place to search out these hidden processes, to search out the weaknesses of the controlling forces, to use his intellect through investigations and through practices to direct and control these forces to his own particular needs.

The Functions of the Soil

Our present concept of the soil is that it is dynamic, that it has functional parts and functional activities that give it many of the attributes of a living thing and that it functions internally in much the same way as the higher orders of animals. The soil has a skeleton of fine mineral particles that gives a framework, as the bones of animals do to the functional activities. It has tendons and muscles binding the particles of the skeleton in the colloidal material in the soil and it has colloidal linings which absorb and regulate the supply of mineral plant foods. It has a digestive system for bringing about the digestion and ultimate breaking down of all organic matter with which it comes into contact. It has a respiratory system and a circulatory system upon which the digestive system is dependent and it has a distinctive color which gives an indication of the general functional activities of the soil.

The bones of the living animal are probably always changing. The identical atoms of phosphorus and of calcium present in the bones of the young animal are probably not present in the bones of the aged animal, as there has probably been a continual replacement and repair work with increasing age.

The skeleton of the soil, the rock fragments, are likewise undergoing a wear and a constant replacement. Through solution and oxidation and attrition due to many causes the particles wear down until finally the minutest particles of mineral grains are broken down by water and the silicon, aluminum and iron form colloidal solutions, while the calcium, potassium, sodium and phosphorus form true solutions in the water. The greater parts of these elements, however, are immediately withdrawn from true solutions and are absorbed in the colloids in which they become relatively inactive. When the concentration of the true solution is reduced, sufficient of the absorbed material is released to make up for what has been withdrawn. This is the solution equilibrium between the true solution and the colloidal solution. As the soil colloid is many thousand times more attractive for the mineral elements than is the real solution the colloid constitutes a vast reservoir for maintaining a real solution of nearly constant composition in which the concentration of mineral matter is extremely small but sufficient for the need of the plants. The colloidal linings around the roots of the plant can not take in material held in colloidal solution.

It is the wearing down and the final change of state of these mineral particles, the death of the mineral cell, so to speak, of the soil skeleton that provides the mineral material for the growth of plants. So the individual particle of the soil skeleton must die and must change its form in order that the plant may grow.

The unused portion of the soil mineral which dies, that portion which is in excess of the needs of plants or which is returned to the soil after the plant has finished with it and after the plant dies and is digested into its original components through the digestive action of the soil, is not lost but re-appears for man's use either to re-enter plants or to form mineral deposits or to assist in the formation of sedimentary rocks. Soils resulting from these sedimentary rocks have lost so little in the economy of nature that the ultimate composition of the rocks is not materially different from the original rocks. New minerals are also constantly forming in the slow re-combination of these mineral elements in the soil or in the new sedimentary rocks that are being formed. So the soil is constantly going through a cycle in which at a certain point it contributes mineral elements needed by the growing plant.

The soil has a closed circulatory system such as the animal has, as a means of conveying the soil solution to all parts. It is like the circulation of the blood in the veins and arteries and capillaries of the body to supply material and to remove waste material and generally to assist the digestive system of the soil. The animal has a closed circulatory system, but there is a great deal of waste in the evaporation from the skin and in the respiration through the lungs. To overcome these losses the animal is given a supply of water at intervals. In going over a desert water holes must be available at certain intervals or the animal perishes for lack of sufficient water to maintain its so-called closed circulatory system.

In the same way there is leakage from the surface of the soil through direct evaporation. There is a drain also on its circulatory system by the transpiration through plants. If the rains do not come at sufficient intervals to replace these losses the circulatory system in the soil becomes low and digestion may be suspended. On the desert these soil losses through leakage far exceed the supply, the circulatory system is impaired, the digestive system is stopped. The only resort under these conditions is the installation of an irrigation system through which the circulatory system of the soil may be maintained in order that the plant may obtain its needed water supply and the digestive process in the soil may proceed.

The soil has a respiratory system, for the soil organisms that are most effective in the digestive system of the soil are dependent upon an interchange of gases, the supply of oxygen and the withdrawal of carbon dioxide, as the animal is in its functional activities. The respiratory system in the soil is dependent in part upon its texture and upon its colloidal content, in other words, it is dependent upon what we call the structure of the soil. Not infrequently in low positions the soil becomes saturated with water and remains so for long periods or even indefinitely as measured by the span of human life. Under these conditions it is like an animal with its lungs full of water, the soil is drowned, it has no respiratory system. Under these conditions the digestive system of the soil may proceed along certain lines, may accomplish certain results, may produce certain relatively useless vegetation, but it will not produce the valuable plants that domestic animals and man need for their food. Under these conditions the thing to do is to provide artificial drainage to carry off the excess of moisture, to introduce an artificial respiratory system that will permit of the normal functions of a soil of that particular type.

The digestive system of the soil, as before explained, acts in the same general way as the digestive system of the animal. It is of much greater magnitude and in the end even the most resistant organic material is broken down and resolved into its simplest forms. We are not yet familiar with the details of the digestive processes in the soil any more than we are with the digestive processes of the animal body. The soil is the home of bacteria, enzymes, yeasts, molds, protozoa and other forms of life. We have not only not listed and classified these forms, but seems to be performed by relays. Changes go on and are arrested through the absence or inability of the relief force to complete the work at a particular stage. Sometimes there appear to be conflicting forces, one set of forces being more effective under certain conditions, and at other times and under other conditions another set of forces having control. Under swamp conditions the more easily digested materials of the plant like the sugar and starch, proteins and the fats, may be digested in one way or another while the organisms for the digestion of fiber may be lacking or inactive. Under these conditions fibrous peat is developed which persists for long periods and accumulates to great depths unless the soil is suitably drained. Our coal deposits are due to this arrested digestive system where the digestion has proceeded almost as long as the oxygen content of the organic matter persisted and the material was reduced almost down to the hydrocarbon stage, the material then being covered over to preserve it from all possible biochemic action, in which form it has been preserved to us as a source of fuel. These are extreme illustrations of the effect of arrested digestion in the soil but in our cultivated soils these pauses or lapses frequently appear to occur, representing a sort of indigestion which brings about a fatigue of the soil as we have a fatigue of the muscles of the animal where exercise is so violent or so long continued that the bodily functions can not rapidly enough dispose of intermediate forms of waste material.

In the modern study of the chemistry of the organic matter of the soil the Bureau of Soils has isolated some 35 organic products that have clearly resulted from the digestive processes. Some of these, such as creatinine, a nitrogen body, are distinctly beneficial to plants. When we add creatinine and nitrate of soda to plants growing in separate solutions the one appears to be as beneficial as the other. Whether the creatinine is taken up as such by the plant or whether it is broken up into simpler forms of nitrates before it is absorbed by the plant, we do not know. We only know that it has about the same availability in supplying nitrogen to the plant as has nitrate of soda.

On the other hand we have isolated other organic compounds, such as dihydroxystearic acid, which are exceedingly toxic to plants even in very small amounts. The occurrence of this material is generally associated with soils that show a characteristic fatigue or exhaustion and are not adapted for example to commercial wheat growing. Other forms of organic compounds separated from the soil appear to be harmless and without effect upon the plant. Why toxic organic material should develop in certain soils we do not know any more than we know why eggs or butter or lobsters are sometimes the cause of violent indigestion with some people and under certain conditions.

In the digestive process of the soil, therefore, the digestion may be arrested, the line of degradation of the organic matter may be affected, so that the products of digestion may at all times be either beneficial or noneffective, or it may be in a line that is distinctly unfavorable to a given crop.

We have seen that the ultimate direction and effect of the digestion of the soil is to resolve the organic matter into simple forms of carbon dioxide, water and mineral elements which the plants can use over again in their elaboration of organic matter in their leaves during the daylight. Apparently the carbohydrate, exclusive of the fiber, and the protein and fat bodies are the most easily digested by the soil as they are by the animal, and apparently the soil digestive system is most eager to separate first the oxygen, either with or without sufficient hydrogen to form water; i.e., as the degradation goes further and further the material is left weaker and weaker in oxygen and approaching closer at all times to the hydrocarbons. These hydrocarbons or material approaching that class appear to offer the greatest resistance to digestion and it is this class of materials approaching the hydrocarbons which accumulate especially under grass vegetation as the basis for humus. The humus thus formed is generally beneficial to the soil, is innocuous as regards the plant and is the immediate form of sewage disposal in the soil.

The Digestive System of the Soil

The seat of the digestive activities of the soil must reside in or on the soil colloid. It can not take place inside or even on the clean surface of the mineral particles. It can not take place in the air spaces or the so-called voids. It can not take place in the free water of the soil for at optimum moisture content where the soil is at its best condition for plant growth, the water in the soil appears to be entirely taken up or absorbed into the colloidal material. The only place where it could proceed therefore is in the colloidal mass. We can conceive therefore of the colloids in the soil, so disposed as to be thoroughly aerated and having sufficient organic matter to provide the organisms with sufficient energy for growth, to be a seething mass of fermenting material in which the organic remains of plants or of animals are being systematically torn apart as they are being resolved into the simple forms of carbon dioxide and water.

The organisms themselves are of a colloidal nature and undoubtedly form a part of the soil colloid. We know nothing about the physical structure of the enzymes or ferments, but, whether or not they have a shape or form, they are of a colloidal nature.

The energy required for the life, growth and activities of these micro-organisms comes from the breaking down of complex organic compounds built up originally by the higher order of plants, into the simple forms of carbon dioxide and water out of which the higher order of plants originally built up the material. In the breaking down process the mineral elements appear to be as necessary as they were in the building up process. In an article in *Science*, August 25, 1922, I estimated that the Miami silty clay loam soil, contained 19.3 per cent of colloid, contained about 60,928 pounds of potash (K_2O) in the unaltered minerals of an acre-foot of soil, that it contained 19,522 pounds per acre-foot of potash in the colloid, and about 27 pounds per acre-foot of potash in free solution. Plants can absorb the element potassium only from that contained in this free solution, although the free solution in the soil can obtain potassium from that in the colloid to replenish that which has been absorbed by the plant. The potassium which enters the plant, however, comes immediately into contact with colloidal material, is constantly associated with colloidal material while remaining in the plant, and is probably at all times itself in a colloidal state.

Potassium salts in free solution have very active chemical powers. When potassium salts are withdrawn from real solution into colloids or colloidal solutions they are extremely inactive in their chemical powers and affinities. In this colloidal state, however, they appear to have remarkable powers of acting as catalysts in helping to bring about changes and transformations in which they themselves do not take a constituent part. In the colloidal state therefore they appear to be most active and efficient as catalysts having lost most or all of their powers of chemical reactions which they exhibit when in real solutions. The cause of this difference in their capacities to act is not understood, as the chemistry of the colloids has never yet been worked out.

The 60,928 pounds per acre-foot of potash in the unaltered minerals of the soil above referred to play no part directly in the soil economy, but that portion of the potassium which resides in the colloids and is not directly available to the growing plant must play a very important part in the digestive system of the soil. The potassium is in the colloid and has itself taken on these colloidal powers which have just been explained. There is this difference, however, that in the plant the potassium is contained in a mass of organic colloids while in the soil it is contained in a mass of mineral colloids composed mainly of silicon, aluminum and iron. Aside from this difference in the nature of the colloidal material with which it is associated the state of the potassium is the same within the plant as within the soil colloid. The breaking down of organic matter by the soil organisms is therefore unquestionably assisted by the mineral elements in a colloidal state in the soil colloids. In the case of the soil above referred to there is over 19,000 pounds per acre-foot of potash alone to assist the soil organisms in breaking down the organic matter. The potassium in this form has lost many of its characteristic chemical powers which we recognize in free solution but has those mysterious powers acquired through its change of state of acting as a catalyzer in tearing down the complex organic molecules in order to provide the energy for the growth and activities of the digestive agencies.

The growing root in contact with the soil has of course an immunity from the destructive action of the soil's digestive system, as the growing cells of the animal are immune from the destructive powers of its own digestive fluids. There are opposing forces, the growing root taking advantage of the digestive system in the soil so long as it is growing, throwing off into the soil dead cells or dead tissues which it no longer needs and which the soil quickly digests, but with the death of the plant, with the permanent cessation of growth the dead stuff is quickly attacked and is used as food material to supply energy to the soil organisms.

The yeasts, molds, protozoa, bacteria and other agencies of decay do not all wait in the soil for organic food to be brought to them. The spores of these organisms, wafted by the winds, are everywhere present and may begin their work on a dying branch of a tree high up in the air. They are like scouting parties, always on the search for food, always ready to begin their work of destruction as soon as the work of construction has ceased. After they have seized their prey, it is not long before they are able to drag it to the earth and to complete their work of the transformation of the energy of the sunlight in the great cycle which has been outlined.

The soil organisms as a rule appear to have a short span of active life, a few minutes may see their birth, period of activity and their death, but with budding and cell divisions they multiply with enormous rapidity where they have sufficient of the proper kind of food, where a proper respiratory system is provided, where a sufficient circulatory system is available and within comparatively narrow ranges of temperature.

The kind of food each can digest appears to vary as it varies with different kinds of animals. They vary with their requirements of a respiratory and of a circulatory system as do animals. They vary enormously with the temperature changes. The increase of a few degrees in temperature will put a quietus on certain organisms and bring others into active conditions and so, as the temperature of the soil rises in the daytime and falls during the night, it is probable that different agencies are effective throughout this range on the temperature scale. These soil organisms have this peculiar and important difference from animals and from the higher order of plants. They produce spores which may remain inactive for great periods of time where the temperature or the moisture content is unfavorable to their active life and can immediately attain this active state when their normal conditions of growth return.

Such is the history of the vital processes going on in what we term the digestive system of the soil, so far as we can vaguely see it. What now can man do in controlling and directing these forces of nature to his own advancement?

Methods of Cultivation and of Cropping

Man has a limited control of the digestive activities of the soil, as he has of the digestion of animals through proper exercise, which tends to speed up the circulatory system and the respiratory system, through proper food and through the application of mineral elements.

Plowing has a number of effects. It is a means of regulating the surface, of throwing it up into ridges and gradually forming terraces. It turns under and incorporates the remains of previous crops. In turning over the soil in the process of plowing it exposes it for a time to the air and promotes oxidation as exercise does in the animal. It leaves the soil for a time in a loose and friable condition in which the circulatory system may become more rapid and more effective. It tends to leave the seed bed in a loose and friable condition for the young seedling. All of these effects, it can be seen, are advantageous either to the young seedling plant or to the digestive activities of the soil in promoting for the time a more rapid oxidation and in affecting for the time the circulatory system of the soil.

Subsequent cultivation of the soil is but a modification and extension of the original plowing. It is confined more closely to the immediate surface of the soil to prevent excessive injury to the developed root system. It has an effect upon the circulatory system in that, if properly done, it tends to prevent leakage or loss of water from the zone of active root development. It is also a means for the extermination of weeds which, especially in the early stages of the growth of a crop, may be extremely prejudicial.

The Romans knew that certain associations of plants were prejudicial to the crop yields. They knew that trees had to be given a certain space and that certain crops could not be grown in close association with trees, not only on account of the shade afforded, but because the drippings from the leaves of the trees, if planted too close together or too close to cultivated crops, tended towards injury. These matters have been recently investigated and it has been found that the drippings from the leaves after a rain and the water which descends on the outside of the trunks are often distinctly toxic to crops with which it comes in contact. It has been shown that where weeds and corn are growing together so that their roots can intermingle, neither the weeds nor the corn make as large a growth as where the roots of one are separated from the roots of the other.

There are certain crops, however, that do better when grown in association, such as timothy and redtop, blue grass and white clover, timothy and red clover. The Chinese have taken advantage of this principle and grow even their cultivated crops in associations where they are able to help each other in their struggle for existence. The reason for this has not been fully determined. Whether the roots of one crop throw off excreta that are beneficial or deleterious to the roots of the other, whether it affects the digestive functions of the soil by giving two kinds of food material at once to be digested, has not been determined.

When a mature peach orchard is cut down it is generally believed that a new peach orchard can not be successfully introduced until, after a lapse of 10 or 12 years, the digestive system of the soil has finally succeeded in removing the last traces of the previous crop. With the growth of the original orchard there seems to have been an accumulation in the soil, or there seems to have resulted a change in the digestive functions of the soil that is unfavorable to the growth of seedling trees of the same nature until time permits of the complete elimination of the substance added or a readjustment of the digestive functions that will again permit of the same kind of tree being successfully grown. This appears to be the principle for crop rotation — either the natural rotation of forests which may have a period of 300 years or the rotation of annual crops which may have a period of but a single year.

The fathers of some of the older men now living in western New York have stated that in their youth the country was covered with a dense growth of fir and of spruce as of the time when Cooper wrote his Leather Stocking Tales, while now that growth has been entirely replaced by hardwoods, such as oak, maple and ash.

In the Island of Sumatra the excellent quality of tobacco continues to be produced only three or four years, after which the jungle is permitted to take possession of the fields for a period of 12 or 15 years, apparently owing to the fact that the digestive system of the soil becomes impaired with the cultivation of this cultivated crop and the jungle growth is resorted to to restore the balance that is required for producing the highest grade of leaf.

In the long-time series of plot experiments that have been carried on in this country a simple three-year or four-year rotation of crops seems to have been as effective in increasing the yield of any particular crop as has the application of commercial fertilizers on crops continually grown. Where both rotation and fertilizers have been used about twice the increase has been secured as where one or the other method has been used separately.

It has been shown in plot experiments where cowpeas have been continuously grown crop after crop that the digestive system of the soil is unable to keep up with the accumulation of organic compounds given off by the plant, that the continuous growth of wheat crops has the same effect upon the soil, but that a wheat crop following a crop of cowpeas seems to benefit by the material that was deleterious to the crop that left it there. Whether the wheat crop, following the cowpeas, actually feeds upon the excreta of the previous crop or whether it assists in some way the digestion of this material in the digestive system of the soil is not known.

The organic substances vanillin and dihydroxystearic acid are extremely toxic to the wheat plant even when present in the soil or in the cultural medium in very small amounts. An application of nitrate of soda almost entirely neutralizes or destroys this toxic property. Whether it directly neutralizes the effect of the organic substances on the roots of crops or whether it assists the digestive system of the soil in the digestion and breaking down of these bodies is not known. Neither potassium nor phosphorus in any known combination has the same effect on these substances.

Quinone is another very toxic organic substance when, even in dilute solutions, it is brought into contact with the roots of plants. Potassium compounds neutralize and practically destroy this toxic influence. Whether it acts directly on the compound or assists the digestive agents of the soil to quickly destroy it is not known. Neither nitrogen nor phosphorus compounds have any such effect.

Coumarin, another toxic organic compound for wheat, becomes harmless in the presence of phosphoric compounds while potassium or nitrogen compounds have little or no effect. Whether the phosphorus compounds themselves destroy the coumarin or whether they assist the soil digestive system to quickly destroy it is not known. It seems probable as we shall later show that it is the digestive system of the soil assisted by the phosphorus compounds that accomplishes the result.

The Romans knew that certain types of soil were inadapted to certain crops. The trend of thought now is that this inadaptibility is due to the inadaptability of the digestive system under the conditions under which it works to function in the necessary way and with the material associated with that particular form of plant.

We have in our animals and birds digestive systems that are quite different; some can digest mainly starchy foods, some require the seeds of plants, some live only on the flesh of other animals. We must remember this when we are talking about the digestive system of the different types of soils. The one we see clearly as we arrange the food to be given to support the life of the animal in its infancy and in its growth. The other we can not see, but we have strong grounds for suspecting that there are similar differences in the digestive systems of different soil types and in the digestive systems required by different crops.

The effect of irrigation and drainage in maintaining the proper balance between the circulatory and respiratory systems in the soil has already been referred to, and they have been shown to be important methods in the regulation of the digestive activities of the soil.

It will be seen that all of these methods of control point to a decided influence in the control of the digestive system of the soil. Sometimes one or another of these methods may be the controlling factor in crop production, often they are interchangeable, equal results being apparently obtainable from either of two or more methods. Usually the best results can be obtained by the intelligent use of all methods.

We come now to the consideration of the application of fertilizers and fertilizer materials to the soil and it will be seen that in large part this is but an extension and an addition to the other methods of cultivation, in that a large part of the effect is apparently due to the control of the digestive system of the soil.

The reason for taking this view will be shown in part at this place and in part when we come to discuss in detail the plot experiments which have been carried on since 1844. In the first place all soluble mineral elements that are added to the soil are almost immediately absorbed into the colloidal material of the soil and are themselves held in a colloidal condition. The potassium salts and such of the phosphorus compounds as are soluble are taken up thus with surprising rapidity. The organic nitrogen compounds are themselves colloids. Nitrate of soda is apparently taken up by the colloids but the nitrate in this form is not so strongly held as the potassium or the phosphorus.

When these mineral salts are absorbed into the colloidal material profound and mysterious changes take place. They lose in large part their generally recognized chemical properties and they give up their ordinary chemical affinities. When potassium chloride has entered the colloid, the chlorine which was chemically combined with the potassium loses the support of the potassium element and as it is not held very tenaciously in the colloid it becomes free to wander at will and is eventually largely removed through the drainage waters.

Neither sodium, nor nitrogen in the nitric form are very strongly held in the colloidal matter of the soil. Neither of them are so strongly held as potassium or phosphorus or calcium. Whether they actually lose their bond of union as does potassium nitrate when it enters into this state of matter is not known, although it seems highly probable that to a certain extent this takes place.

The introduction of these mineral salts and their entrance into the colloidal state brings about a mighty change. Their former affinities in the sense of consorts are loosened if not entirely separated. Their consorts that may be separated from them require time to disappear from the scene of action. They shoulder and push aside portions of other mineral elements which have previously occupied situations that they wish to occupy. These changes and readjustments require days and months to be fulfilled and it is in this period of change and readjustment that their most active influence seems to be felt. Are they more active and more efficient in their work during this period o change? Is the potassium that enters the seedling plant equall effective during the entire period of growth? We know that i both animals and plants there is a constant exchange of th mineral elements. They are being eliminated by both plant and animals. Is this elimination because they have exhauste their capacities to work even in the colloidal material and tha fresh mineral elements are required to carry on the function that they began? Is this what we mean by stimulation in re lation to fertilizers, soils and crops?

We have shown that mineral elements are essential in th breaking down of organic matter as in building them up, bu always so far as we know it is the mineral elements workin under colloidal conditions. We have shown that they are als used as buffers to protect these activities where large amount of leguminous crops are added to the soil. Acid products ma be formed in the process of digestion in the soil as in the plants So in the soil the continuance of activities may depend upon th buffer effect of certain calcium compounds or of certain potassiun compounds in protecting the plant or the soil organism from a undue accumulation of their acid products, so that the function can continue.

It must be remembered that the soluble salts we add in ou fertilizers stay but a very short time in the free solution wher they might be available to a plant, while with incredible swift ness under normal conditions when they are taken up by th circulating medium, they are absorbed by the colloid in whicl state they are not directly available to the plant, but are i exactly the state in which they are needed by the soil organism to assist them in the breaking down of organic matter fron which they derive their energy. Therefore it seems highl probable that a large part of the effect of fertilizers is on th soil in aiding and directing the digestive system rather tha directly upon the plant.

Aside from the potassium, phosphorus and nitrogen compound which we commonly class as fertilizer materials, trials have bee made of a great number of mineral and organic compounds often with beneficial effects, often with deleterious effects. The beneficial effects of manganese in some of its forms have been so pronounced as to lead many to believe that its use might be justified as a recognized fertilizer constituent. The same may be said of common salt. Traces of copper, arsenic, and sulphur have been used often with beneficial effects although it is known that for the first two named substances the addition of considerable amounts is highly deleterious. Small traces of arsenic are often administered to the animal or man with beneficial results and in certain abnormal conditions while larger amounts are invariably deleterious or even fatal in bringing about a complete cessation of the functions and the death of the person. The use of certain disinfecting reagents, of chloroform, of methods of sterilization to kill some of the antagonistic forms of micro-organisms in the soil, have been tried with more or less success in controlling the digestive activities of the soil.

Material which is passed through the animal body, with or without bedding of waste organic materials, mixed more or less with juices and ferments of the animal digestion is an especially favorable material for use on the soil. It is partially digested already, appears easily digested in the soil and appears to be a material that is especially beneficial when added to the digestive system of the soil. Thus stable manure appears to be a most favorable food material for the digestive organisms in the soil.

We have emphasized the importance of the soil digestive system as a general scavenger to convert all waste plant material, animal material and dead animals themselves into the simpler component parts which plants can again use as material suitable for their growth. If this energy cycle were not finally completed, if dead plants and dead animals accumulated without going through this process of decay, there would finally come an end to the carbon dioxide supply in the atmosphere under normal conditions and there would be a cessation of plant growth and of animal life. This digestion process in the soil must, however, go on without the formation of injurious products and with the formation of the most beneficial products possible for the growth of plants.

It has already been stated that under continuously saturated soil conditions the products of decay, that is, the digestive process, is generally unfavorable to the higher order of plants. There is required always for the best results a certain balance between the respiratory and circulatory systems of the soil.

It has already been explained that the roots of plants by reason of the colloidal nature of their outer skin do not take up from the soil material in a colloidal form, but that materials in true solution enter the plant root more or less freely according to laws pertaining to the passage of soluble matters through colloidal membranes. In other words the plant, like the soil colloid, has the power of selective absorption and can take in potassium and exclude at least a portion of the chlorine with which it was previously combined. If the free solution in the soil is heavily charged with mineral matters, the plant has only a limited power of preventing an accumulation of mineral elements within itself that may be decidedly injurious. If the soil solution should be too weak, material may pass out of the plant in such quantities as to be detrimental. Thus the value of the great reserve in the soil colloids to maintain the concentration of the dissolved material at a nearly constant level adapted to the needs of the plant.

The colloidal lining of the plant root is in certain respects extremely delicate and fragile. Corrosive substances coming in contact with it may modify or destroy the membrane as such substances may irritate and destroy the protective skin of the animal. The plant may take up soluble organic bodies which may be toxic to it by inhibiting the normal process of growth or it may take up organic bodies of such a nature as in themselves can be directly applied and used in the life processes of the plant with or without modification. There seems to be no reason to doubt that some of the organic products of digestion of the soil may be directly assimilated by plants in this way and used in building up its tissue or in providing energy to the plant in the night-time when the plant is deriving its energy from the breaking down of organic matter which it had previously built up.

It has been shown in a previous chapter that certain salts of nitrogen, potassium and phosphorus appear to have a very certain action on organic matters, which without their presence would have a deleterious effect upon plant growth. We have also seen the buffer action of certain basic salts of calcium which benefit the soil through the neutralization of the acid formed permitting the soil organisms to continue their work and preventing soluble acid products from entering the plant. We have also shown that other salts besides those recognized as fertilizer materials, such as the manganese salts, traces of copper, may at times accomplish results which seemingly can not be brought about by ordinary methods of cultivation or of fertilization. At present we have no reliable methods which will enable us to forecast the results of the application of any fertilizer constituent and must content ourselves with the knowledge gained through experience.

In view of the foregoing explanation, it seems a very narrow view to take in calling fertilizer constituents "plant foods," as their action and effect is far broader than the narrow interpretation usually ascribed to a food product.

The Origin of Fertilizer Plot Experiments

It is thought by some that the Egyptians, Greeks, Romans and Chinese had experimental fields where they tested varieties of crops, crop adaptations, crop rotations, cultural methods and the application of fertilizer materials. Whether or not this was done through organized effort or merely through the interest and caprice of individuals is not known. The origin of our present plot experiments with fertilizers, however, goes back to the year 1844 when Sir John Lawes established his famous plot experiments at Rothamsted, England, which have been continued with only slight modifications to the present time. All of the plot experiments begun since then have been based essentially upon the plans and conceptions which were formulated at that period. It has been pointed out in a previous chapter that this work was started just after the appearance of Liebig's celebrated book on "Chemistry in its Relation to Agriculture and Physiology," and in the first period of our knowledge of the chemical constitution of plants. The discovery of the principal chemical elements had but recently been announced. Chemical methods had just been worked out. The chemical analysis of soils and of the ash of plants had just been accomplished. No idea of the important field of biochemistry existed. It was a period when the soil was considered a static thing, when the fertilizer material was added as a distinct plant food which the plant could take or could leave alone as it wished. The plant food elements added to the soil and not taken up by the plant might be stored up in the soil substantially in their original forms for the use of future crops or it might be leached out of the soil through percolation. Little or no attention was given at that time to a consideration of possible influence of fertilizer constituents upon the soil, except the physical effects that might be derived from marl, lime and organic matter.

There were of course people even then who were not satisfied with such a simple explanation. They were particularly curious as to the mode of formation of humus in the soil, the constitution of humus, the part it played in the economy of plant growth. A great scientific controversy was precipitated on this point which was not settled until Pasteur discovered the cause of fermentation and various biochemical reactions began to be understood. There were controversies on the variation in the ash constituents of plants, of the availability of the mineral constituents of soils. It was a period of scientific unrest based upon partial knowledge. Wonderful progress was made by the men of that period. Their discoveries, their concepts and their methods were epoch making and were of a high standard, so far as their knowledge or powers of observation had developed.

Other lines of chemical science were worked out in the same perfection according to their knowledge at that time, which have been materially changed with our present broader concepts of the nature of material, of the constitution and properties of the atom, of the perfection of methods and of theories, but we still admire them for what they did in directing the minds of men to a truer concept of the nature of material things.

In other lines of chemical endeavor, however, with increasing knowledge and with perfected methods, we have changed our views, we have changed the old methods, adapting them to our present knowledge, but the plot experiments with fertilizers have not been changed with increasing knowledge, but are formulated on exactly the same principles and with the same ideas that prevailed in 1844.

The Romans knew that cultural methods must be adapted to the kind of soil, that they must be modified according to the system and to the condition of the soil and they knew that the variations in cultural methods must be adjusted from time to time according to the judgment of the master mind. They looked upon this as a matter requiring the most skillfull judgment, such as was required in their military campaigns or such as is required by a navigator of a ship to take advantage of the varying winds and currents. No formula could be written by them for the cultivation, including manuring, of a piece of land for a period of years in advance. It is impossible in human experience to prescribe a course of living for the youth, which must be followed inviolate through the entire period of life without leaving to judgment deviations made necessary through the changing conditions that influence that life as the years go on.

If the soil had been a static thing uninfluenced by the changing climatic conditions, uninfluenced by the character of weeds and of the development of the plant, uninfluenced by the character of the vegetation and the development of the plants during the preceeding or earlier years, if it had been uninfluenced by anything but the material added, then we might have hoped to prescribe a course which should be followed without variation during a series of years. But the soil is dynamic, it is always changing, it is influenced by many things, it is not wholly dependent upon substances we add as fertilizers.

The English farmer modifies his method according to slight changes in the mechanical condition of his soil, upon the appearance of new weeds or an excessive growth of weeds. He modifies his methods with the general appearance of the crop, its vigor of growth, its color, its vitality. He resorts to many variations in his treatment of his soil which could hardly be made in the rigid control that has to be exercised on a long continued fertilizer test plot.

The official in charge of a series of long time plot experiments sees influences at work, changes occurring, which his judgment as a farmer indicates should be met in a way that the conventions of the scientist do not permit. He sees influences at work that affect his crop which he is not always able to combat through the radical means which would be employed by the farmer. He sees that other things are affecting the yields besides fertilizer added yet he is powerless to change his methods and is helpless in the control of these other controlling factors.

These things must be remembered when we come to discuss the long time fertilizer plot experiments. Some of them are inherent to the method and can not be avoided. Some of them perhaps can be controlled if a little more flexibility be given to the plans. Most of them could probably be avoided if we understood more fully the action of fertilizers and the place they take in our cultural methods.

The Results of Plot Experiments

It must have been in the minds of those who started the earliest of our modern fertilizer experiment plots, looking as they did upon the soil as a dead and lifeless thing, with the mineral plant foods as the limiting factor of plant growth, to expect that if they took a plot of fair size to which they added no mineral fertilizer constituents and plots of equal size to which they added different amounts and different kinds of fertilizer materials, cultivated and cropped them in the same manner, the differences in yields would enable them to determine the specific fertilizers required for different plants. Later it was felt that the fertilizer requirements of a crop on one type of soil might not be the same as the fertilizer requirements on a different type of soil. So experiments were started in Germany, in France, and in the United States to see how the results agreed with the results obtained at the Rothamsted Station. It was then felt that as soils are known to be more or less ununiform in different parts of a field instead of having a single unfertilized plot they should have a number of unfertilized plots distributed throughout the experimental field. They did not, however, consider it necessary to have duplicate plots for any of their fertilizer treatments.

It may, therefore, be stated that the expectation has been that the fertilizer plot experiments would show the specific requirements of different crops and of different soils.

Such simple and valuable results would probably have been obtained if the mineral plant food had been the sole controlling factor, as Liebig and some of his contemporaries seem to have assumed. They knew, however, that there were other factors of growth that at times operate to limit the development of crops. The climate, including both the temperature and the rainfall, they knew to be controlling factors. The adaptation of soils to crops, the rotation of crops and the various cultural methods employed were known to have an influence on crop production. These things they ignored, feeling that so long as the rain fell on the unfertilized plots and the fertilized plots alike, and as the methods of cropping were the same, that the only substantial difference between the unfertilized plots and the fertilized plots would be the difference in the amount and kinds of fertilizer materials added to the fertilized plots.

They did not then know that the rainfall affects not only the plant but the organisms of the soil. They did not then know that all cultural methods would affect the organisms of the soil as well as affect the plant itself. They did not know that the larger growth of the plants on the fertilized plot would affect the soil organisms to a different extent than would the smaller growth on the unfertilized plot, that the larger plants would put a greater strain on and yet give more energy to the digestive system than would the smaller plants on the check plots. They did not know that the character and relative vigor of weeds on the one plot might put a load on the digestive system different from that on another plot. They did not know that these various forces in the soil and methods of control are in a measure interchangeable and have much the same effect on the crop yield whether one or another is used; or that they might have additive effects, each method producing something independent of the other or that they might have opposite effects, the effect of one neutralizing the effect of another method. Finally they did not appreciate the complexity of the whole system and that the differences in growth between the fertilized plot and the unfertilized plot would be the resultant not only of the difference in the fertilizer added, but would be due to the summation of all of these interrelated factors in the soil as well as in the plant itself.

We shall see, as we develop the story of the plot experiments with fertilizers that have been carried on for the past 80 years, the evidences of controlling factors apart from the fertilizers added which explain why the long-time fertilizer plot experiments have been of the utmost value to scientists, but why they have not met fully the requirements of practice, and why we have not yet reached a point where we can state with assurance the fertilizer requirements of different soils and of different crops.

From the static point of view virgin soils, where no crops have ever been removed from the surface by the hand of man, should be the most productive, as they have sustained no loss of plant food due to cropping since the beginning of agriculture and they have the accumulation of ages due to the weathering of soil material.

This is not in accord with human experience. Fertilizer plot tests have been made in most of the countries of the world. It has been found that the virgin soils of Alaska, of Africa, of Australia and of South America respond to fertilizer applications as do the older agricultural soils of Japan, or of Europe, or of the United States. We often hear of these virgin soils producing satisfactory crops introduced by man for two or three years and then of the yields declining until after a period of four or five years the crop fails to make any satisfactory growth. From the static viewpoint this is incomprehensible; from the dynamic viewpoint it is easily understood. From the static viewpoint it is inconceivable that garden vegetables consumed on the farm or field crops that are sold from the farm may in the course of four or five years show in the soil evidence of a decline that can be ascribed to the loss of accumulated plant food of the ages, which has been sufficient for the native vegetation of the region.

From the dynamic viewpoint the soil has adjusted itself through these ages to a natural growth of native vegetation. When man turns over the virgin sod and suddenly changes in an arbitrary and artificial manner the character of the vegetation by sowing the cultivated crops of maize, of wheat, of barley or some of the cultivated grasses he changes entirely the relation of the soil to the crop, he changes the character of the food presented to the soil organisms. In changing the character of the vegetative growth he changes the digestive system that has developed for the wild plants and expects it to quickly adjust itself to the requirements of the artificial crop. So on soils that may be very productive for jungle or native grasses, applications of fertilizers or of manures may be beneficial and may be necessary to regulate soil conditions so as to adapt the digestive system to our cultivated crops. It is worth while noting here the belief of the Japanese that their oldest soils, which they believe have been under agricultural occupation for as long as six thousand years, are the safest and the most productive soils generally because they have long been under control, have been thoroughly regulated and are well understood, as they have descended from father to son for many generations. They dread to take up virgin soils for they recognize that to get them under control and to acquire a knowledge which will make them safe and permanently productive requires generations of crops and generations of men who work the soils in continuity. Many cases have been reported where peat soils full of organic matter after being drained are unproductive for cultivated crops, especially after two or three years unless applications of potash salts or easily digested organic matter in the form of stable manure are applied to the land. It is easy to see with our present knowledge that the potash salts may assist the digestive organisms in breaking down certain organic compounds which they have been unable to dispose of readily unassisted and the presence of which may be detrimental to growing crops. The introduction of stable manure, as an alternative method of control, appears to carry the explanation that there may be organisms thus introduced in the manure that can effectively handle the organic substances which were prejudicial to crops or that the application of the easily digested organic matter by feeding the soil organisms might bring such an amount of energy into the system that the digestive system of the soil might itself accomplish the desired results unaided by the potassium salts. The organic matter which had accumulated in such quantities in the soil under adverse soil conditions of complete saturation with water was a poor food for the soil organisms, otherwise it would not have accumulated to such an extent. The introduction of additional organic matter fully charged with active organisms and with available food for the soil organisms after a proper circulatory and respiratory system had been established through drainage has been responsible for the improved conditions.

We can never expect through any method of control known to us to get all types of soils equally well adapted to a particular crop any more than we could expect to get all types of animals to digest equally well any particular kind of food, nor should we wish to accomplish this end, but within the natural limitations of the soil types and their functional peculiarities we should strive to determine the best crop adaptations for each type and the best treatment for the soil for the particular type of crop it is adapted to grow. In all human endeavor the object is to classify and regulate and improve animals according to their several capacities. In the education of our children, in the assignment of our men and women, we recognize this same principle of adaptation and capacity for training and for application in industrial pursuits. The same fundamental classification and utilization of our different soil types should underlie the proper organization of agriculture to the extent of human knowledge and of economic conditions.

From the results of many thousands of plot experiments that have been carried on in the United States it would appear that the effect of fertilizers is much the same when applied to very productive soils as to soils of low productivity, indicating that they have an office to perform, that they find something useful to do in soils which yield 50 bushels of corn or in soils yielding 10 bushels of corn per acre. In the one case, however, the result is relatively small and insignificant. An increase of 5 or 10 bushels per acre in a soil producing normally 50 or 60 bushels per acre of corn is, under our present system of agriculture, relatively unimportant, but such an increase of 5 or 10 bushels on a poor soil, which without fertilizer produces only 5 or 10 bushels of corn, increasing the crop by 50 or 100 per cent is relatively a very important thing and may mean the difference between financial success or failure on the part of the farmer.

In this stage of our knowledge of the use of fertilizers there naturally arise fads and fancies which spread often from a single case and from a single season which sweep over communities and take entire possession of the thoughts and beliefs of the people for a time. We see this in our everyday life in regard to human foods, the place of milk in the diet, the superiority of whole wheat bread, the importance of bran, the belief that a fish diet supplies phosphorus to the brain, the contrasting of a meat and a vegetable diet. Quite recently there has been a fad for eating yeast as a result of the importance of our recently acquired knowledge of vitamines. And so these fads and fancies go, influencing our lives and our habits for a short time, to be superseded by some other idea or fancy.

So in telling a simple story, as this is intended to be, of the place of fertilizers in agriculture, it is difficult to separate facts and fiction. It is difficult to write a story which will not appear to conflict with the fads, fancies and beliefs that are held, because of the limited knowledge we possess and because we can not see facts in proper perspective.

Raw sulphur has been found to be beneficial on certain soils and under certain climatic conditions and the idea quickly spread throughout the civilized world that this may be the limiting factor in all soils, that this may be the elixir of life, the one thing that will give general and universal satisfaction. The farmers in one section of the country come to believe that acid phosphate is the only thing that need be added for the wheat crop, others that raw rock phosphate gives better results than acid phosphate. In some sections the idea prevails that fish scrap is the best form of nitrogen, in other sections that it should not be used under any conditions. And so these fancies arise and spread and are forgotten as the styles for clothing change from period to period, each with its strong advocates and usually without reason or facts to justify.

We have recently passed through an era of fierce competition in the sale of commercial fertilizers based upon the strength of passing fancies and judicious advertising. The " Red Lion " brand is shown to be much more vigorous and much more reliable than the " Black Sheep " brand sold by a competitor. The name carried the sale without consideration of the composition of the material sold. The " Corn Booster " may have exactly the same composition as the " Excelsior Wheat Grower " but it carries a difference in meaning and has an effect upon the sales of the material. Such brand names and their " good will " have been capitalized for millions of dollars as an asset on the books of many fertilizer companies. Such things are common to all walks of life, to all lines of human endeavor and of human experience.

The examination and analysis of thousands of plot experiments which have been carried on in this country indicate that in the case of corn where a single mineral element is applied to the soil in any of the recognized forms of commercial fertilizer material, the chances are 2 to 1 that an increase of crop will be obtained. Where a mixture of two elements is used the chances are 6 to 1 that an increase of crop will be secured. Where three or more mineral elements are added the chances are 12 to 1 that an increase of crop will be secured. In the absence of specific information to the contrary one would be rather foolish not to take the safer course of 12 to 1 and use a mixture of three or more chemical elements for corn.

In the case of wheat the chances of an increase are 2 to 1 for a single element, 5 to 1 for a mixture of two mineral elements and 18 to 1 for a mixture of three or more mineral elements.

In the case of cotton the chances of obtaining an increased yield with any one single element is 4 to 1. With two elements it is 10 to 1 and with three or more elements it is 154 to 1.

Knowing what we do about the intricacies of the soil digestion, the influence of climate and of cropping, the struggle for existence by the organisms in the soil digestive system, the pauses and hesitations in the digestive process, it certainly seems reasonable, if we have no specific knowledge to the contrary, to expect that a mixture of the three elements nitrogen, phosphorus and potassium in appropriate combinations would be safer than the use of any single one of these elements.

Very little definite information has been obtained from the plot experiments as to the effect of the different compounds of nitrogen and potassium, especially, or as to the effect of different proportions of the three elements that should be put into a mixture, probably because the methods of plot experiment are not sufficiently refined and because other limiting conditions of plant growth have rendered it impossible to distinguish between the effects of different substances. This is not at all surprising when we consider the intricacies of the subject. We have the same difficulties in prescribing a food diet or treatment with drugs, which have to be modified according to the constitution, peculiarities and idiosyncrasies of the human person. These idiosyncrasies must be understood or experiments must be cautiously tried out to arrive at the proper diet or the dosage each individual requires. Not only this, but the response of the same individual may vary in different periods of life or under different conditions of metabolism.

Science has progressed through the perfection of instruments of precision and the methods for the use of these instruments. The exact determination of our unit of measurement, the meter, with which our yardsticks are directly or indirectly compared, was a matter that received the grave consideration of the best scientific minds of the world. This international unit of measurement accepted by all the civilized world has been placed in a subterranean vault in the City of Paris with infinite precautions to prevent changes of any kind in its length. From this were developed our units of capacity and our units of weight, which are likewise preserved with the utmost care.

In our ordinary commercial transactions we do not use these instruments of exact precision for in measuring clothing a yardstick that is approximately correct is all that is necessary, or in weighing sugar or in measuring vinegar such exactness is neither necessary nor advisable. But when the tolerance becomes too great and false measures are used the very foundation of business integrity is destroyed. If the yardsticks were indiscriminately twenty-four inches or forty-five inches in length and it depended on chance which of these were used our buildings would be unsafe, our engines would not operate and our commercial transactions could not be carried on in a legitimate way. The same thing would happen if the weights representing a pound should vary from thirteen ounces to thirty ounces and were used indiscriminately for weighing out materials.

In our plot experiments the unit of measurement is the unfertilized plot or the check plots scattered through the field. If this basis of measurement is not reasonably exact then, we can not hope to secure exact and reliable figures from the fertilized plots. Where we have only one check plot there is no means for determining the accuracy of the measure. Where we have two or more check plots we have a means of determining the accuracy of the method at least as between the different check plots.

The following diagrams show the differences in yield of bushels per acre of corn on the individual check plots as compared with the average yield of all the check plots in two experimental fields.

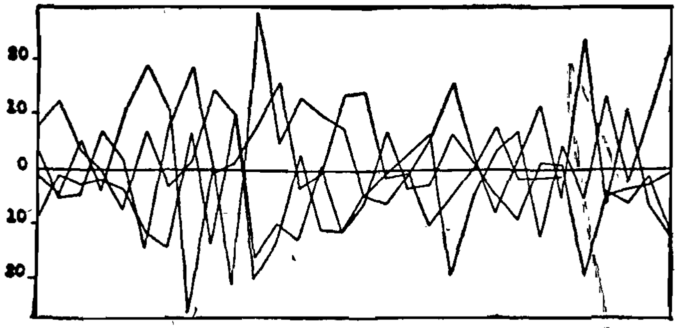


FIG. 15. Difference between average of check plots and each check plot.

The one is a record of four check plots over a period of thirty years, the other a record of fourteen check plots over a period of nineteen years. Corn was grown on all of these soils under a four-year rotation in figure 15, and under a five-year rotation in figure 16, there being four or five series of plots, so as to bring a measure of corn for each year during the entire period.

Heretofore our story has proceeded smoothly, like a murmuring brook or like a stroll through a meadow, but with the introduction of these figures it appears that we are coming on rough ground with mountains and deep depressions that make it appear that we will have rough going. In the past we have travelled over some rather thin ice but it was level and smooth and we tried to help the reader along so that he would not realize the dangers and mysteries over which he was passing. If we could only travel over the straight line that represents the average of the check plots it would be so easy a path that we could span the periods of nineteen or thirty years covered by the records in the same quiet and prosaic style of the previous narrative, but when we examine this apparently straight line of averages we are compelled to see that storms are coming up, that the road is getting very rough and the going difficult.

The average yields of the check plots are prepared as a convenient measure or yardstick with which to measure the increase of yields on the fertilized plots. This average, however, carries nothing in itself. It is not an observed yield but the average of the yields of all of the check plots in any particular year. If the different check plots are not approximately of the same yield then the average of the check plots, which constitutes our yardstick, will not be reliable. In the same year the yard measure of one check plot may be ten or twenty bushels longer than the average or ten or twenty bushels less than the average, so that the average which constitutes the yardstick we intend to use is made up from yardsticks of the several check plots which vary greatly, a condition that would not be tolerated in trade or in commerce. It appears therefore that the average yield of check plots which vary as much as these individual check plots vary does not constitute a reliable measure. If we compare the yield of a fertilized plot with the average of the check plots and find a difference of twenty bushels of corn which we ascribe to the use of fertilizers a comparison with a single one of the check plots which was twenty bushels above the average would show no difference while a comparison with another single check plot in the same season might show a difference of forty bushels of corn. The only thing to do would be to use the average of the check plots and to have as many check plots as possible from which to derive this average. This we know, however, to be a mere quibble for where the different yardsticks differ as much as these the average can have but little value. It seems therefore that before we can expect to measure with any degree of exactness differences in fertilizer effects we must give particular study to the cause of these variations in the unfertilized plots which are to be used as a measure of the fertilizer efficiency, and if possible change our methods or change our ideas so as to get more reliable measures for our plot experiments.

It is presumed that in selecting the field for this fertilizer plot test extending over thirty years (Figure 15) great care was taken to select a field of uniform soil conditions in every part. The results indicate that the field selected for the thirty-year experiment was fairly uniform. The average yield of these four plots for the thirty years of the experiment was 41.5, 49.0, 44.2, and 48.3 bushels per acre. In each year these four check

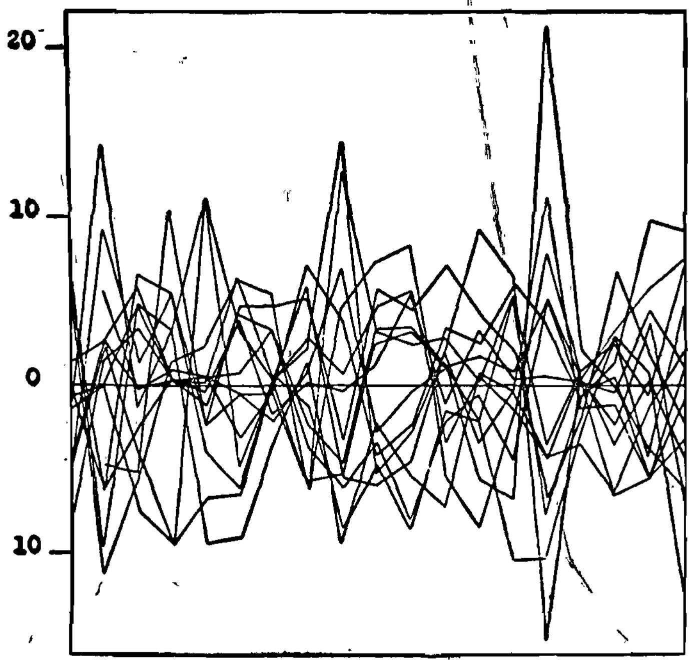


FIG. 16. Difference between average of check plots and each check plot.

plots have fluctuated violently but in the course of thirty years the ups and downs have compensated each other to a remarkable extent. In figure 15 there can be seen little evidence that some of the lines are continuously above and some continuously below the average but the characteristic thing that appears from the figures is a succession of surges and recessions. The individual plot that gave the highest yield in one year may give the lowest yield the next year and so they go surging along above and below the average in a bewildering way. What causes these surges and recessions; what is it that affects the length of the different yardsticks from year to year? The plots are in an apparently uniform field, they are close together, they have the same rainfall, they are under the same temperature conditions, they have presumably the same cultivation, the same seed, the same rotation of crops, and yet they vary as much from season to season as the differences between the average of the check plots and the average of the fertilized plots. What causes this variation in the unfertilized plots?

Before we attempt to explain this or to comment further upon these results we will present a few charts showing the effect of fertilizers on the soils and then having thrown all our cards upon the table opportunity will be presented for a general discussion of the whole subject.

The two diagrams which follow show the differences between the average of all check plots, which is represented by the straight line which forms the base of the figure, and each of the fertilized plots where complete fertilizers, that is, where all three of the mineral elements have been used over a long period of years. The straight lines drawn through the figures from the first year to the seventh year in one case and to the twelfth year in the other, and from these points to the end of the period of record will be called the straight line average. This line has not been drawn with any pretense of mathematical accuracy as it is intended to show only the general direction that the figure takes.

One can not fail to realize that the simple story we started to relate is getting very complex at this point and these strange and weird drawings are tending to make the visibility exceedingly low. In these two figures the action of the fertilizer appears to reach a maximum point after seven years of continuous application in one case and after twelve years in the other. From this point in both figures the line lies parallel to the average of the check plot but as the check plot is continually falling in productivity during this period the straight line average of the fertilizer plots also falls in like manner from the maximum point to the end of the experimental period. This is brought out very

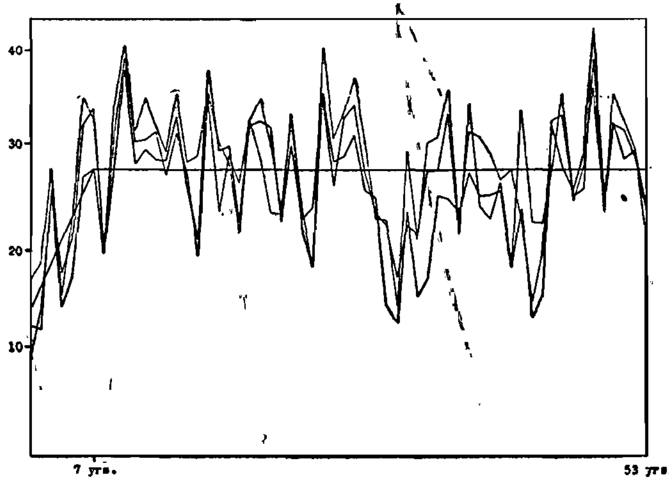


FIG. 17. Continuous culture in barley 60 years. Increase of complete fertilizer plots over check.

clearly by the drawings in figure 19, where all of the annual fluctuations of both the check plots and the complete fertilizer or manure plots are omitted for the sake of simplicity.

The first point to be brought out is the fact that the effect of fertilizers is marked by a succession of surges and recessions. The periods of high efficiency are followed by periods of low efficiency. Sometimes these are annual changes, sometimes one or more years may intervene between the high points and the low points.

It further appears that it requires from five to fifteen years of continued annual application for fertilizers or manures to attain their maximum effect in increasing crop yields over the yields of the continuously unfertilized check plots. It further appears that this accumulative effect is not a regular increase as would be expected if the soil were a static thing but that the

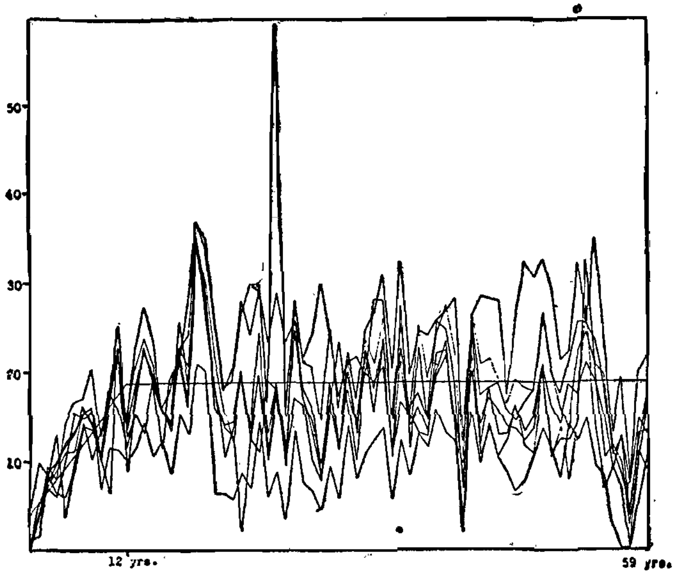


FIG. 18. Continuous culture in wheat 71 years. Increase of complete fertilizer plots over check.

increase is accomplished through distinct surges and recessions until finally it reaches the high point. This indicates at once a determining influence over which we at present have no control. Throughout the whole period of the experiment this subtle influence is at work, giving us a succession of high and of relatively low efficiencies. In figure 18 about twenty years after the experiments were started there was a year when all of the fertilizers showed their highest efficiency. There are two years in the latter part of the period when the fertilizers showed a very small efficiency.

In the outline drawings of figure 19 in all cases but the last three drawings, one of which was for a short period of seventeen years, the continuous application of complete fertilizers or of

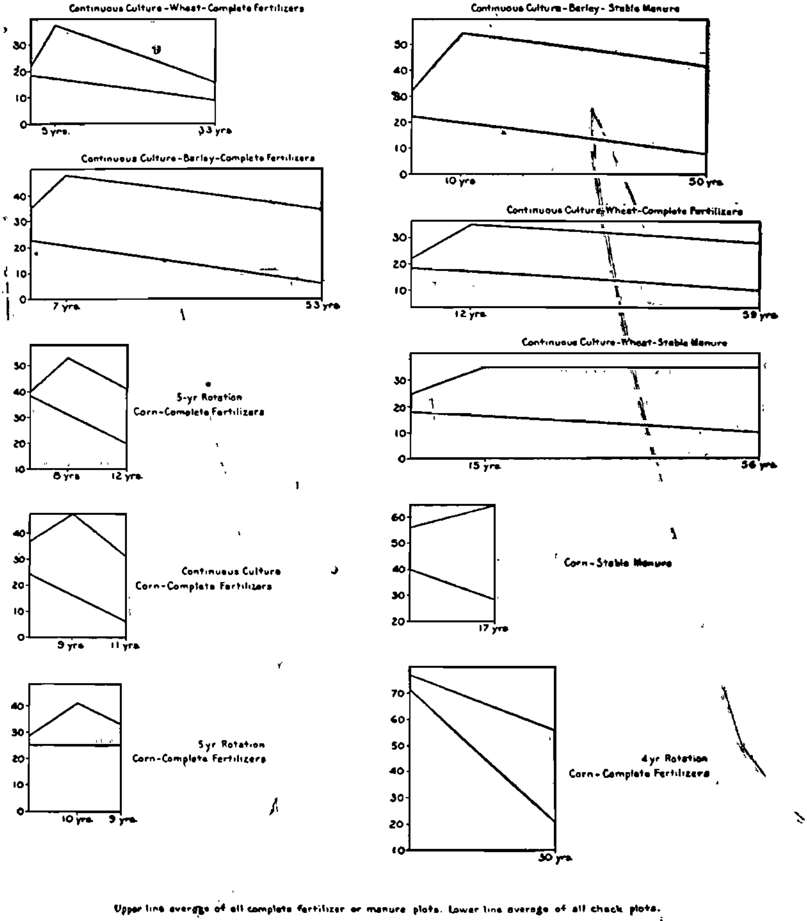


FIG. 19. Yield of crops (straight line averages) with and without complete fertilizers or manure.

stable manure have reached a maximum after from five to twelve years, after which the yield of the fertilized plots has continued to fall at the same rate as the fall of the check plots or even faster. This fact is outstanding either where the crop has been under continuous culture or where it has been under a system of rotation.

What causes this fall in the yield on the fertilized and manure plots when year after year the same generous applications are made to the soil? What readjustments are taking place in the soil that is tending to diminish the efficiency of fertilizer action?

There is only one outstanding case where fertilizers have been used for a number of years, then withheld for a period, and reintroduced and where the crop has been measured from year to year over all of the time. The results of this are shown in figure 20.

It will be seen from this that in spite of the fact that the fertilizer had been added to the soil annually for a number of years the stoppage was followed by an immediate collapse of

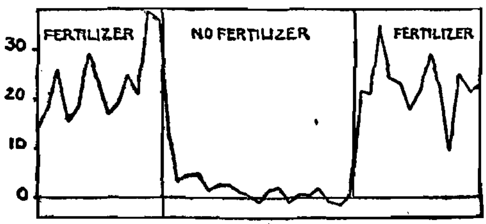


FIG. 20. Intermittent use of fertilizer.

the yields to the level of the check plots while their renewal restored the yields as quickly to the former level. The accumulation of mineral elements from previous applications appears to have had no effect over the period where the annual applications were suspended. From the meager information available the same results appear to follow in the case of organic manures such as rape cake but to be much slower in falling off in the case of stable manure.

It might be supposed that the differences in the efficiency of the fertilizers and manures might be due to climatic conditions but the surges and recessions are too violent and too regular to be explained by differences in climatic conditions from year to year. Furthermore if the series of plot experiments are arranged in order of yields of the check plots from the lowest yields to the highest yields, the yield of the fertilized plots arranged in the same order of years is approximately parallel showing about the same influence of good and bad seasons on the fertilized plots as on the unfertilized plots. This is a very important point for it shows that the actual yields on the fertilized and on the check plots are affected about alike with the changing climatic conditions. Therefore these surges and recessions in the differences between the yield of the check plot and of the fertilized plot, where the effect is shown on one and not on the other, can not be due primarily to climatic conditions.

It is a fortunate thing that we spent so much time in describing the functional activities of soils and especially in describing the digestive system of soils for it appears now that we have in the first part of our story, where we discuss the biochemical factors which were discovered during the period from 1860 to 1900, shown clearly the fallacies of the earlier school that considered the soil as static and we can see a reason for the vagaries in the results of plot experiments that have been carried on without reference to the most recent work of soil science. We can see in these surges and recessions evidences of dynamic forces and changes in the functional activities of the soil over which we have as yet not been able to secure adequate control.

If we take the results from the unfertilized check plots we must see in the case of a single plot that in one year it is in condition to produce a maximum crop while in the following year the condition is changed and it can only produce a minimum crop, as though the strain put upon the soil by the production of a larger crop, notwithstanding the fact that the larger crop furnishes more food material for the soil organisms and more energy for their growth, leaves the soil less effective for a season, or more and smaller crops result.

It has been stated that these fluctuations have apparently no relation to changing climatic conditions. The fluctuations among the duplicate check plots shown in figures 15 and 16 are far greater than we would expect to find in a field uniformly cultivated. The annual fluctuations in the duplicate check plots therefore appear to be due in part to the fact that these small plots are set off by themselves and in large measure are cultivated and cared for as though they were independent fields and that by reason of this fact the plants on the one check plot are subjected to somewhat different influences than those on other check plots. This is in spite of the fact that so far as it is humanly possible the cultivation has been the same on all of the plots. The result of even slight injury to the plants on one plot from insects or from disease would be likely to disturb the balance in the soil. The struggle for existence among the soil organisms, the rapid development of bacteria followed later by an equal development of their predatory enemies, such as the protozoa, might account for these vagaries.

We see all around us in our everyday life illustrations of these fluctuations — the large crop of certain apple trees generally followed by a small crop the next season, the swarms of insect pests like the tree caterpillars which, after a year or two are suppressed by the proportionate development of their parasites, the surges and recessions of fever in some of the diseases of the human body, the immunity for a series of years following the inoculation of the human being. Everywhere in the living things of nature we find these surges and recessions, especially among the small bodies and in the less highly organized forms of life.

The digestive system in the soil is so complex, the individual organism is so responsive to slight changes of food, to slight changes in temperature, to slight changes in acidity within the food material and they are dependent for their life and activities upon the life and activities of other species that work with them or against them according to circumstances that there is every chance for expecting variations such as are shown.

The variation in the yields of the check plots may come from slight variations in the health or vigor of the plant (or of the soil) which was grown the year before or several years before that may have escaped our observation. It may be due to slight differences in cultivation or in treatment. It may be due to slight differences in the vigor of the plant in different stages of its growth or development either of the present crop or crop or crops that preceded. There is undoubted evidence of material differences that tend to lengthen or to shorten the yardstick by which we measure fertilizer efficiency when we compare the yield of the fertilized plot with the yield of the check plot.

So we have the surging effects shown in the differences between the yields of the fertilized plots and the yields of the check plots. We have the surges and recessions during the earlier years of the application when the differences as a whole are getting wider and we have the same surging effect in after years as the differences in yields are on the whole constant or are getting less and less as time goes on. In some of the recessions the fertilizer seems to have little or no effect. In years of pronounced surges the fertilizer seems to have a great effect. What are the digestive conditions in years when fertilizers have their maximum effect and in years when they appear to have their least efficiency? These are problems that must be understood before we can have a rational system of fertilization. Can we perfect a method which will indicate the needs of the soil, which will show in advance of the planting season whether the soil is in a condition to respond to fertilizers or not? Is there any method of diagnosis through which the responsiveness of the soil can be predetermined, as we diagnose an animal or a man in order to arrange a suitable diet or to decide on the administration of a drug?

The countries of northern Europe have increased their average yield of wheat from about twelve bushels per acre to twenty-eight or thirty bushels during the past three hundred years. The yield of wheat in the United States has been increasing during the period of reliable statistical records. Both in Europe and in the United States the increase in yield is apparently slowly continuing. In most of our long-time plot experiments there comes a time after from five to fifteen years of continuous treatment either with fertilizers alone or with fertilizers and rotations combined when the yield reaches a maximum and then begins to decline. What readjustment takes place in the soil at this point that our prearranged treatment does not meet? It is not due to an injurious accumulation of fertilizer residues for apparently if we withhold the fertilizer the yield at once falls and is restored again by the resumption of the fertilizer treatment. But why should the yields decline after reaching a maximum and what has the English gardener, the German farmer, or the Chinese farmer been able to do to keep the yields slowly but continuously increasing?

After the maximum effect has been obtained, in from five to fifteen years, does the experienced farmer note a difference in the condition of his land, does he note a difference in the appearance of his crop, does he note a difference in the character or growth of weeds that suggests to him the necessity of a change of cultural methods or of crops or of fertilizer applications? The descriptions that accompany the annual reports of the long-time plot experiments indicate that they do notice differences in the tilth of the soil, in the character and growth of weeds through the continuous and unvarying character of cropping and fertilizer treatment. With the scientist these things have to be met as best he can without material change in the system predetermined years before. The farmer, free from these conventions, is able to change his system and in some way he has been able through these adjustments to lead his soil continuously onward to a higher and higher point of efficiency.

In the planning of future long-time plot experiments would it not be well for us to make provision in at least a portion of our experimental fields to vary our cropping system and where the maximum effect of one system has been attained, as indicated by a gradual fall in yields, that another system may be introduced adapted to the particular soil type and based upon observed differences in the character of the soil and in the character and condition and appearance of the crops?

The long-time plot experiments have indeed furnished a world of valuable information. They have demonstrated most clearly the importance of the use of fertilizers among the cultural methods within our control. The world to-day is satisfied that the use of fertilizers has been a great boon to agriculture, that it is a method which if intelligently used permits us to obtain results in a fraction of the time that would be required by other methods of cultivation. But because we have been thinking of the fertilizer material always as plant food and of the soil conditions as being static we have not derived the nice distinctions and the definite control that is required in practical life. Let us drop the term "plant food" as applied to fertilizers. Let us recognize the significance of the biochemic factors of the digestive system of the soil and let us recognize the interdependence and the correlation which exists for the best effort of the soil, the plant and the fertilizer treatment.

CHAPTER V

THE DEVELOPMENT OF MAN ON THE EARTH AND THE BEGINNINGS OF ORGANIZED AGRICULTURE

THE early records of the existence of life on the earth must be attained through the study of rocks and the occasional remains of plants and animals embedded and preserved in the rock material. This has been very fragmentary for it is very laborious work and in only rare cases were the conditions favorable to the preservation of the records. It may be possible in the future to write a fair history of the development of life and to understand something of the scheme of development. At present we have only the most fragmentary knowledge of facts. The facts so far ascertained indicate that life has progressed through surges and recessions, a form suddenly appearing, increasing in population and as suddenly disappearing with apparently a long interval before another form appears, develops and as suddenly subsides.

The first chapter in the Book of Life gives evidence of plants with no animals, first the water plants and then the land plants. The second chapter shows the lower forms of animal life, especially marine life and then the land life.

The Eocene period, the dawn of recent life (an abundance of mammals); the Miocene (with more of recent life) the great age of mountain building; and the Pleistocene (with a majority of recent life), during the latter part of which period occurred the great ice age, constitute the great chapters leading up to the advent of man. In the Pleistocene period North and South America appear to have been in open and easy communication with Europe, Asia, Africa and Australia after which the ice age and the Bering Sea together shut off all direct communication between the Eastern and Western Hemispheres. The world to-day is coming slowly out of the last of four great waves of ice.

The finding of crude stone implements in the beginning of the Pleistocene period, which is estimated by geologists as occurring 550,000 years B.C., makes it seem probable that this was the period when man first appeared on the earth. This is estimated at about 50,000 years before the first glacial period.

It must be remembered that the pages of geologic history most carefully preserved are those that occur along the margins of the swamps of that period where decay is retarded or impeded, as animals that live and die in the open most frequently have their bodies entirely devoured or consumed by natural agencies. About the only other way in which records have been preserved is in caves where there has been some protection from the destructive elements.

The first glacial age is estimated by geologists to have occurred at about 500,000 B.C., the second glacial age at about 400,000 B.C., the third glacial age at about 150,000 B.C., and the fourth and last glacial age at about 50,000 B.C. There was, therefore, an interglacial period of 100,000 years between the first and second glacial ages, 250,000 years of interglacial period between the second and the third glacial ages, 100,000 years between the third and the fourth glacial ages and 52,000 years since then.

The earliest bones that may possibly have belonged to man appear to be contemporary with the first ice age in point of time and were found in the Island of Java. The second interglacial period is represented by a jawbone found in a sandpit near Heidelberg, indicating that if it is in fact the jawbone of a man he must have lived some 200,000 or 250,000 years ago. The next record of human remains is supposed to have been in the third interglacial period which is between 50,000 and 100,000 years ago.

Such is the fragmentary evidence of the records of man's antiquity as determined by the fragments of skeletons. After this we have no records for many thousands of years indicating the existence of man except flint instruments which improved steadily in quality as time went on.

The origin of man and the original center of distribution of men on the earth has been traced to a point in southwestern Asia somewhere in the region around the northern boundary of Persia and Asia Minor. It is supposed that they dispersed from this point in all directions over the earth, that the successive changes in the earth's surface and in the climatic conditions, the retreat and advances of forests and of game, the encroachments of arid plains, the advance and retreat of ice operated to disperse man until finally the earth was populated in all its parts. It is supposed that in the Pleistocene period there was a pathway of dry land that would permit access to the Australian Continent to the south and to the North American Continent to the north and that the successive changes of climate and of game facilitated and encouraged the movement of people to Africa, Asia, North and South America and to Australia. After the first ice period the Bering Sea opened and separated the Eastern and Western Hemispheres and about the same time Australia was disconnected from Asia. After this hundreds of thousands of years pass before we come to the earliest dawn of history, recorded first in the crude images on stone and later in the expression of thoughts, ideas, and facts in the writings of conscious and intelligent men.

Scientists are slowly but gradually accumulating the fragmentary record of the rocks, are studying the characteristics of the peoples of all continents, in an effort to unravel the story of the development of man, to trace back the origin of the natives of Patagonia, the different tribes of Indians of North America, the different nations of Europe, of Asia, of Australia and the different races of Africa. They use in this research the size and shape of the skull, the development of the teeth, the size and the arrangement of the bones, the instruments of warfare and of domestic service, the folk lore of the people, the monuments and carvings, the habits and the language, all traits and characteristics which appear to show a relationship which runs back for hundreds of thousands of years to a common origin with the people of southwest Asia.

There is one clear cleavage that runs through the whole race of man, one part has been sedentary in its habits, has been distinctly social in its feelings, has wanted to settle in communities and till the soil, while the other part has been nomadic, always wandering, always on the go, living on the wild things of nature or upon flocks and herds, and always at warfare with the sedentary people. Dr. E. F. Gautier of the University of Algiers in an article on the Nomads and Sedentary Folks of Northern Africa in the *Geographical Review* for January, 1921, says that the nomads have a saying that " shame enters the family with the plow." The nomad is referred to as " the people of the sword," or as " the people of the tent." The tent is as respectable as the house. Even now to the Algerian nomad the towns are " nauseating." A nomad tribe ruined by losing its camels and consequently its mobility enters upon sedentary life with rancor in its heart. It is the supreme humiliation and irretrievable loss of caste.

The earliest intellectual, written history of mankind probably lies with the Chinese, who claim in their oldest writings that their culture dates back to 10,000 B.C. The Chinese claim their earliest history gives a suggestion of a far higher civilization and of intellectual knowledge of inventions and of practices than that possessed 100 years ago. The traditions of the Egyptians, of the Persians, and of the other old races of Asia suggest that there may have been in the far distant past periods of intellectual thought, of knowledge, of material accomplishments, which have been lost to us because of the destruction of records. At the present time this is purely speculative. The pyramids of Egypt in their details of construction, the engineering features involved, the mechanical and astronomical precision of their construction have long been felt by the scientists of the world to point back to a period of civilization greater in many ways than the period of known history of that country. Other monuments, inscriptions and works of art lead us to speculate as to the stage of intellectual development that may have existed in the past and been forgotten.

It is easy to forget things that have long since passed, in the complete absorption of the present and the anticipation of the future. The period we are talking of was before the art of writing was invented. If after the fall of the Roman Empire and the 1500 years of the Dark Ages which followed, it had not been for the invention of the alphabet by the Greeks, derived perhaps by them from the Phœnecian and Egyptian discoveries of papyrus and of writing, would there have been an obliteration of the history of the world before the birth of Christ as complete as separated the world then from the world hundreds of thousands of years ago when the Bering Sea was open? What a marvelous occasion the landing of Columbus in the new world would have been if there had been anyone present in the new world who had the memory of their European ancestors from whom they had been separated for hundreds of thousands of years! What a reunion it would have been! A single change in the configuration of the earth wiped out completely all knowledge even of the existence of their early ancestors. What dark ages in the past beyond the dawn of modern history, in the interglacial periods, in the changes of the climate, in the scourges that have even in historic times passed over the earth might have cut us off as though a veil had fallen obscuring an intelligent record of the past. No one yet has satisfactorily explained the cause of the discontinuance of plant and animal life in the past. Even in the present we have seen the sudden and mysterious disappearance of the buffalo from our prairies of the West, and the sudden disappearance of the wild pigeons of a century ago.

Fortunately for us a few written records were preserved during the latest of the Dark Ages and it has been possible mainly through the Greek and Latin writers to connect up with the past and reconstruct at least a dim outline of the history of the world through what we call historic times. These written documents which have been preserved to us furnish a fairly satisfactory basis for at least sketching the progress of mankind during what seems to us a remote period of from 8,000 to 10,000 years and, what particularly appeals to us now, give a basis for sketching the history of agriculture and the endurance of the soil during those historic times.

It has been shown that it is our present judgment that the center of distribution of the peoples of the world was from somewhere in southwestern Asia. The center of distribution of the intellectual life of the world within historic times was in a belt bordering the Mediterranean and not far removed from the coast on the European and African sides extending eastward through Asia Minor, Persia, India and China. It is to this belt that our histories pertain and from the histories of these people that we must draw our knowledge of the agriculture of the past and judge of how the soil has endured under long usage.

One peculiarity about this belt of intellectual development is that during historic times it has been a belt generally of low rainfall and of relatively high temperatures making it necessary over much of the country for people to conserve the rainfall and irrigate the land or drain and reclaim the lowlands adjacent to the rivers. This requires engineering skill and a vast expenditure of labor to install and maintain. It is important to bear in mind the type of agriculture and the engineering work required to farm these lands to properly appreciate how vulnerable the system was upon which society was based to the attacks of ruthless marauders. The castles and fortified towns defended the people of the cities against armies but a vast, intricate and indefensible irrigation system was necessary to protect the life of the whole people against catastrophes of nature. Then we must remember that the desert lands that could not be irrigated were many of them inhabited by wild nomad tribes ever on the move utilizing the scanty pasture for their herds and flocks and greatly despising the people who cultivated the land.

We now have the stage set for the curtain to rise on the great drama of agriculture that will bring us down to the time of the birth of Christ, covering a period of perhaps 10,000 years. The first scene covered a period of at least 500,000 years so this is a much shorter period, but it is much fuller in detail and the more so as the period comes to a close. There will be much fighting and bloodshed, the overthrow of cities and provinces, which we will skip over as rapidly as possible but which we can not entirely ignore as they have an important part to play in the history of agriculture.

Chapter VI

AGRICULTURE IN THE OLDER COUNTRIES OF THE WORLD

We will concern ourselves first with those countries in which agriculture has within these historic times almost completely died out and for this purpose will consider Asia Minor, Mesopotamia, Syria and the Moorish provinces of Spain. We will then take up countries in which the agriculture has been maintained throughout historic times and in this class will consider particularly China, Japan, Egypt, Greece, Rome and Carthage.

In recent years the known decadence of agriculture in the first group of states has been held up as a horrid example of the exhaustion of soils through continuous cultivation without the addition of commercial fertilizers. There is a general belief that the agriculture of the second group of states has been steadily declining for the same reason. It is true that the decline of agriculture in the older countries has been attributed by some to the destruction of forests resulting in periodic floods that have devastated the lands, the impression being given that these floods are greater in recent ages than they were in the past ages of historic times. It is our purpose to examine all of the facts so far as they are available to us to see whether the productivity of the second group of states has been decreasing or not and in general to find out what bearing these conditions may have upon the future of soil productivity in our own country.

In looking over the long period of time of which we have more or less definite information the question of the vital importance of chemical fertilizers of to-day can be quickly disposed of. Through all ages of historic times the people have recognized the value and have practiced the art of fertilization, using such substances and methods to maintain their soils in good condition as may have been available to them such as manure from animals and birds, composts, human excrements, ashes and soot, marl, river deposits, the bones and flesh of animals and fish, leguminous crops, the adaptation of soils to crops, and the rotation of crops, and in fact all of the substances and methods that we now use except the phosphate deposits of our own country which were discovered about 1860, the potash deposits of Germany which were discovered about the same time, the nitrate deposits of Chile which were first used in 1830 and the ammonium sulphate which has been derived in recent years from our coke furnaces. Practically all of the materials used by the ancients were from their own farms and added nothing of material brought from other countries for the fertilization of their lands, as we have done in the past 70 years. There is no question but what the discovery and utilization of our phosphate, potash and nitrate deposits have been very important factors in increasing the yield of crops in the past few years but the knowledge of these deposits was hidden from the ancients, and to say that our modern system of fertilization is essential to the maintenance of the soils of China and of Roumania after these thousands of years is illogical to say the least.

That we who have knowledge of these things must use them and that the older countries of the world must use them in the future goes without saying. In the fierce competition of the world to-day it would be as silly to deny their use as it would be if we denied ourselves the use of the telephone, of the steam engine or of the automobile. We can not put ourselves back to the former use of the horse for general transportation without withdrawing ourselves from the march of progress and dropping out of all reasonable hope of ability to compete in our present period.

The first chapter of this book is on " The Man " and we shall see as we go over the history of the past that the responsibility for the maintenance of the productiveness of our fields rests entirely on the man. It would appear from modern propaganda that the maintenance of life, the maintenance of soil productivity, is dependent entirely upon the use of fertilizers, and this is true of modern civilization. It has become a necessary thing in our present society as it has been necessary for our nations to vie with each other in the building of battleships against which the triremes of Rome and of Carthage with their three banks of oars would be entirely unequal to a contest in modern warfare. The use of commercial fertilizers is an important means of maintaining supremacy in the struggle for existence of modern civilization. But the question is still open, as to whether without their use our soils will become as unproductive as are the soils to-day of the once fertile plains of Mesopotamia.

The idea that chemical fertilizers are a substitute for human endeavor can not be considered for a moment as logical. History tells us that with every invention or with the discovery of any additional means of meeting competition there has been required still more intelligence and still more labor to succeed than was necessary for success in an earlier period. So we can not look upon our modern use of chemical fertilizers as a labor-saving device, but rather as a spur and an inspiration through added knowledge and added power for the reward of still more intelligent labor in our fields.

The agriculture of these ancient countries depended in part upon the climatic conditions, in part upon their soils, and in part upon the inclination, skill, social conditions and political conditions of the men.

The temperature for the most part was warm and equable although there is a distinct belief that during this period, if we go back to the year 10,000 B.C., there have been progressive changes in both temperature and rainfall. We have no precise information but there is some evidence to show that in those thousands of years some of the deserts may have become drier and that the rainfall may have progressively changed, but there is nothing certain. The rainfall over the area that we are now considering has been on the whole rather light with great fluctuations, with occasional cloudbursts or thunderstorms that recur perhaps two or three times in a century that have wrought disastrous consequences to the soils under cultivation.

The ancients recognized differences in types of soil, in fact so far back as 2357 to 2261 B.C. in the period of the Yao dynasty of China there was probably the first attempt at soil classification and soil surveying as it is recorded that the Emperor established nine classes of soils in as many provinces of China and upon this was based the system of taxation.

The yellow and mellow soils of Yung Chow (Shensi and Kansu) were put into the first class, the red, clayey and rich soils of Su Chow (Shantung, Kiangsu and Anhwei) were in the second class, the whitish and rich salty soils of Tsing Chow (Shantung) were in the third class, the mellow, rich, dark and thin soils of Yu Chow (Honan) were in the fourth class, the whitish and mellow soils of Ki Chow (Chili and Shansi) were in the fifth class, the blackish and rich soils of Yen Chow (Chili and Shantung) were in the sixth class, the greenish and light soils of Liang Chow (Szechuen and Shensi) were in the seventh class, the miry soils of King Chow (Hunan and Hupeh) were in the eighth class, while the miry soils of Yang Chow (Kiangsu) were in the ninth class. We find in the writings of the Greeks and Romans a clear recognition of the differences in the productive capacities of different types of soils.

We next come to the consideration of the man himself and his social environments which through all these ages have changed materially from time to time as a result of wars and conquests.

It is impossible in the limits of this book to give any detailed statement of the political changes of occupation of these various countries. This is not a book of history but history is of the utmost importance in the study of the agriculture of these countries. All we can do is to give the briefest kind of references to show some of the great movements and the reader is referred for more details in the study of the historic events of these countries to the many histories that have been written.

Professor Griffith Taylor of the University of Sydney has published in the *Geographical Review* of January, 1921, the results of a profound study of the evolution and distribution of races, culture and language in which he treats as fully as knowledge permits of the original distribution from southwest Asia of people to all parts of the world and of the origin of races and the relationship of man in all parts of the world to-day during the 550,000 years that the records of geology indicate man has inhabited the earth. Without going into any such involved study for our purpose we may content ourselves with the following conventional classifications of man within historic times: Hamitic (Egyptians), Semitic (Jews, including Hebrews and Israelites, Babylonians and Assyrians, Phœnicians and Carthaginians, Lydians and Phrygians), Aryan (Indians, Bactrians, Medes and Persians) and Turanian (Parthians, Chinese and Japanese).

The physical geology of these countries has had an important part to play in the development of agriculture as well as of peoples and these things will be touched on as fully as time will permit and as becomes necessary for the development of our study.

Asia Minor

Beginning with Asia Minor, which is close to the supposed origin of man and the center of distribution of mankind and may, therefore, be taken as an example of the oldest occupied country in the world, the following conditions may be cited.

Asia Minor is the connecting link between southern Asia and southern Europe and is supposed at one time to have been attached to Europe. The western border is very rugged and mountainous with deep indentations of the sea. The general topography is much like that of the highlands of Scotland but with a much lower rainfall. Throughout historic times this portion of the country has been occupied by sturdy seamen who have lived principally on the trade of both coasts of the Mediterranean in competition with the Phœnicians to the south and with other great sea powers. There seems to have been no agricultural life of prominence in this extreme western coast of Asia Minor.

On the east side of Asia Minor are mountains which border the high plateau in the center of the country which is a desert and which has been occupied by nomadic races for the pasture it afforded their herds of horses, cattle and sheep. Extending westward from this high plateau are a series of mountains running east and west to the coast carrying rivers whose valleys have been occupied from time immemorial by farming people. These valleys have been highly cultivated in the past by an industrious people and were the seat of the great agricultural wealth of the country in the time of its prosperity.

Recent explorations have revealed a vast engineering work for the control of flood waters and in establishing an irrigation system for the protection and irrigation of the fields. There are still seen traces on the sides of the mountains of these great engineering works. Sir William Ramsay in "A Sketch of the Geographical History of Asia Minor" published in the *National Geographic Magazine*, November, 1922, gives a graphic description suggestive of a vast irrigation and water control system which had been built up in past ages but which is now totally destroyed. As a reason for this engineering work as a protection to agriculture he speaks of explorations on the slopes and at the foot of the Kara-Dagh in Lycaonia in 1907 where he saw traces of an intricate system of terracing which had been almost completely swept away. In the following year he returned to complete his investigations when he found there had been an unprecedented rainfall, such as occurs only once or twice in a century, and the fields of corn had been completely changed to a waste of gravel which had spread out from a single dry water course and had covered the valley floor with gravel and rock débris.

He mentions the fact that ancient Asia Minor at one time boasted of 230 cities each having its own special coinage and each assuming a certain independence as a free city. It seems probable that the villages were so close together as to make them almost continuous. Their cities were fortified but their irrigation systems were of course unprotected. During the four centuries of Roman occupation the Romans built a great road from Rome to the heart of the country to establish communication with Rome itself. Recent explorations in Asia Minor show the ruins of magnificent buildings, innumerable churches and the remains of great cities indicative of great wealth and prosperity.

The early political history of Asia Minor is still mythical, not having been worked out as completely as the surrounding countries. Lydia, the middle of the three divisions of Asia Minor, is the country made famous by Crœsus. To the east of Asia Minor was Mesopotamia with the Babylonians, the Assyrians and Chaldeans — Babylon associated in our minds with the reign of Nebuchadnezzar, and Assyria with the name Sennacherib. Further east was the Persian Empire made famous to us by the names of Cyrus, Cambyses, Darius, Xerxes, and Artaxerxes. On the south of Asia Minor lay the great unorganized country of Arabia and also Syria, Phoenicia, and Egypt. On the west was Greece with Alexander the Great, and Rome with its brilliant array of generals engaged in building up the Roman Empire. On the north were the nomadic tribes of Scythians of western Asia. All of these countries were in almost constant conflict with each other for domination of the then known world. Asia Minor was in the line of march of many of the conflicts, even of those that were not aimed against her own sovereignty. As a matter of fact, however, through historic times she has been a part of the Persian Empire, the Grecian Empire, or the Roman Empire for most of the time.

These conflicts were aimed at the sovereignty of the State and not against the people. Cities were destroyed and rebuilt. The engineering works connected with their erection were preserved so far as the conflicts would permit and so far as can now be revealed the agriculture of Asia Minor was maintained to the end of the Roman Empire.

As before stated to the south of Asia Minor lay the great country of Arabia mainly desert and inhabited by nomadic races split up into relatively small families of people wandering from place to place with their herds utilizing such scanty pasturage as was afforded by the desert and the more abundant pastures of the oases. There was no organized society until Mahomet arose to organize them into a mighty race. Nomadic people are different, have different characteristics, are inherently different in their modes of living from the agricultural people, for whom they have always had a wild aversion. After the fall of the Roman Empire these nomads began to descend upon Asia Minor and ruthless destruction followed their invasions for plunder.

After they became a factor the Crusades began and the Crusaders marched through Asia Minor in their approach to Syria and the land of Palestine. In all previous wars the armies plundered where they could, and ruthlessly destroyed the growing crops, but it had been considered the ethics of war to preserve the fruit and forest trees because of the length of time required for their reproduction. The Crusaders began by cutting down the olive trees for their engines of war but they ended up by the ruthless destruction not only of fruit trees but of forests to accomplish the utmost desolation of the lands.

After the Crusades were ended the Turkish powers accomplished the final destruction of civilized society in Asia Minor. As nomads they had no sympathy with the sedentary people and the destruction of the latter was final and complete. The Roman road was destroyed and Asia Minor was turned over to the occupation and domination of a nomadic people.

During all of this period of wars we must not forget the pestilences which occasionally occurred. In 701 B.C. Sennacherib's army on its way to Egypt was entirely destroyed by a pestilence. All through that early period we have the record of diseases, of great floods and of notable droughts that have destroyed people by the hundreds of thousands.

Sir William Ramsay has given as his deliberate opinion from recent explorations that the agriculture of Asia Minor can be revived provided an engineering work is performed that will restore the conditions that prevailed at the time of the height of the country's prosperity.

It seems quite evident from all the information now available that the death of agriculture in Asia Minor was not due to a deterioration of the soils but was due to the political changes which finally substituted a nomadic race for the sedentary people that had built up the agriculture and whose engineering works for the production of agricultural crops and for the protection of the fields were destroyed through neglect.

Mesopotamia

Mesopotamia lies on the east of Asia Minor and on the western border of Persia. The borders have changed from time to time in historic times but we will consider Mesopotamia as occupying the valley of the Euphrates and Tigris rivers from their origin as they come out of the high tablelands and mountains of what is now called Armenia to their mouth at the Persian Gulf. This is a country with a most fascinating history, containing as it did the city of Nineveh, the city of Babylon with its enormous wealth and the city of Bagdad with the romantic period of Haroun-al-Raschid. Babylonia was the earliest of the great provinces with Babylon as the capital city and Assyria with Nineveh as the capital arose as a great rival. There were also the Chaldean provinces and many tribes developing from time to time in the Mesopotamia region. Mesopotamia is the original home of the Hebrew race from which their first leader Abraham went out in search of land which he could claim for a heritage for his people.

It is about 800 miles in a straight line from the northern boundary of Mesopotamia to the Persian Gulf. For the first 400 miles southward the country is broken and gradually descends to an undulating surface but below this point the rivers form a vast plain or alluvial flat.

Herodotus tells us that this country was one of the greatest for the production of grain, yielding returns as high as two hundred fold or even three hundred fold in exceptional years. He says the soils were not notable for the production of the olive or other tree fruits. An inventory taken in the time of the early Caliphates showed 12,500,000 acres under cultivation in the southern half of Mesopotamia.

The temperature of the country is high, the records at the Bagdad observatory in 1909 showing maximum temperatures in January of 48° to 65° F. and in August from 104° to 118° F. with a great daily range in temperature between night and day. The average annual rainfall from 1904 to 1910 ranged from 2.78 to 10.23 inches. Sir William Willcocks in his report on "Irrigation of Mesopotamia" published in 1917 speaks of the soils as rather light in texture and states that they carry on the average about 12 per cent of lime carbonate. His analysis of the soils at the present time will be referred to later. Both the Euphrates and Tigris rivers carry at times an exceedingly large amount of floodwaters which unlike the floods of the Nile come at irregular times of the year making it necessary to control the rivers within their banks in order to protect the growing crops. The early records of the country, both historical and as determined by recent explorations, show a vast amount of engineering work in controlling the floodwaters and in the distribution of these waters through a vast system of canals. Many of these canals were large enough for navigation of boats which brought down to the cities the enormous supplies required to feed the people.

When Cyrus was passing the great and celebrated city of Babylon on his march to the dominions of Crœsus in Asia Minor, the country on both sides of the Euphrates was very densely populated the inhabitants being very industrious, peaceable, and living quietly and happily on the fruits of their labor. The country was covered with a vast system of irrigation canals. There was a great trunk canal which went from the Euphrates to the Tigris.

Herodotus speaks of the curious custom in the construction and the navigation of the boats, they having an outer skin which protected them from the water. After being floated down the rivers to Babylon with the products of the country the boats were destroyed but the skins were returned by mules that had been brought down on the boats for this purpose. The story then goes on to describe Babylon itself, a city that is said to have covered an area four or five times as large as that covered by London.

Babylon was surrounded by a great wall said to have been at least 100 feet high and broad enough on the top for a chariot and four horses to drive and turn around upon. It was built of brick cemented with natural bitumen. It had over 100 water gates of brass which could be lowered for the protection of the city from invasion through the river or through the canals. The Euphrates ran through the center of the city. On one side was the palace with its hanging gardens, one of the seven wonders of the world, and on the other side of the river was the great Temple of Belus. The walls of the river itself and many of the principal canals were built of brick cemented by bitumen, these walls being projected upward to confine the water to the channel of the river. A great bridge was built across the Euphrates in the city connecting one side with the other. The walls, palaces and public squares were decorated in the most lavish way with various works of statuary and carvings.

The celebrated hanging gardens were near the King's Palace and consisted of a great platform several hundred feet high built up of arches and terraces rising one above the other with steps. The top of the garden was 400 feet on a side, larger than our present city blocks. Each terrace and the top of the platform were filled in with soil deep enough to grow all sorts of plants and all varieties of trees that could be gathered from different parts of the world. There was an engine provided to lift water to irrigate the topmost portion and the successive terraces. The most skillful gardeners were constantly employed in the care of this huge public park and playground.

Such in brief is the description of the great city of Babylon with at least a suggestion of the vast area of fertile lands maintained by an industrious people. There are also accounts of great reservoirs constructed to control the floodwaters, as the English have in recent years been constructing reservoirs at the headwaters of the Nile to control to some extent the floods of that river.

From Babylonia a few people emigrated and built the famous city of Nineveh not far from Babylon and on the banks of the Tigris and from which was founded the famous country of the Assyrians who have been noted throughout history as ferocious and as outrageous in their conquests of their rivals and antagonists. When Nineveh finally fell the historians tell us the whole world was startled and gave a sigh of relief.

It is impossible within the limits of this book to give even a brief summary of the wars, of the capture of Babylon by Cyrus, of its rehabilitation, of the fierce wars with the Abyssinians, with the Egyptians, the Greeks, the Romans and the Arabs. These histories are written by the Hebrews, by Herodotus and by the later historians and form a most fascinating story of a period associated with our own Christianity and with the history of the Jews as recorded in the Old Testament of the Bible. The destruction of Nineveh was accomplished in 626 B.C., Babylon being destroyed 90 years later by the Persians in 536 B.C.

There were constant struggles from that time until finally the nomadic people coming originally from the deserts of Arabia with their utter detestation for agricultural pursuits occupied the country. After a brave fight for many centuries the agricultural people who had brought the land up until it was spoken of as the Garden of Eden were entirely displaced by nomads. Their works were destroyed and their agriculture was killed — not by the exhaustion of their soils but by the complete change of the inhabitants of a sedentary nature to a race of nomads who despised a farming life.

Fortunately for us the world is taking a different viewpoint on these matters, is looking with a true and scientific mind into the lessons of the past, is realizing the importance of the people and civilized society is taking in the lesson that there is a fundamental difference in men as between the nomadic and the sedentary races.

Sir William Willcocks has made a thorough study of Mesopotamia with a view to the possibilities of reclaiming it and putting it in a position of its former agricultural importance. He has given an elaborate series of topographic surveys and maps. He has measured the discharge of the Euphrates and the Tigris and has analyzed their waters. He has analyzed the soils and describes them as generally a light calcareous loam. He reports that the potash content of the soil varies from .32 to .79 per cent and that the phosphoric acid content varies from .15 to .30 per cent, these figures coming well within the limits of the composition of the soils of the new countries of America. He reports the nitrogen content as being somewhat low (.065 to 1.120) but on the whole he finds no evidence of soil depletion. As a result of his investigation he concludes that the agriculture of the country can be restored provided the irrigation system of ancient times be substantially restored for the control of the floodwaters and for the irrigation of the soils.

Syria

The history of agriculture in Syria, the land of Palestine, the country so dear to the hearts of the Jews and of the Christians follows directly the conditions that have been cited for the decline of agriculture in Asia Minor and Mesopotamia. The same armies passed across its boundaries — the same countries were fighting over its head. It was the direct object of attack for many years by the Crusaders. It has finally come under the occupation of nomadic people but there is the same promise of rehabilitation of its agriculture as has been pointed out in connection with Asia Minor and Mesopotamia.

We have the story of Abraham, the patriarch of the Jews, leaving Babylon somewhere about the year 2000 B.C. to seek a land for his own people. We find them first migrating to the land of Goshen in Egypt, and we have the story of Joseph. Then the story of Moses conducting the Hebrews out of Egypt about 1320 B.C. Then the story of the Israelites under Joshua after a long nomadic life in the peninsula of Sinai and on the east of the Jordan about 1250 B.C. conquering the Promised Land of Canaan. We have the story of their conflict with the Philistines.

Then the reign of Saul as King of the Jews somewhere about 1065 B.C. Then comes David and Solomon and the division of the kingdom of the Jews. Then the history of the kingdom of Israel under the prophets and the history of the kingdom of Judea, the wars with the Assyrians, with Nebuchadnezzar, King of Babylon, with the Egyptians and with the Romans — then the birth of Christ.

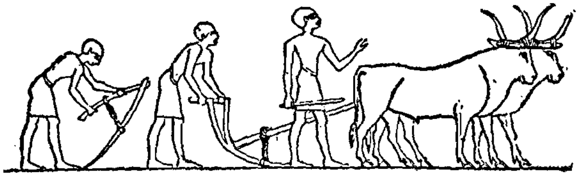


FIG. 21. The ancient form of plow and hoe. (Plows not differing greatly from this are still in use by primitive peoples.)

We have evidence in recent explorations of great engineering works for the irrigation of their lands, of terraces, of flood control, of wells for the irrigation of lands too far from the rivers. We have some record of their fight against the encroachment of the deserts through irrigation from wells which they often found submerged with the sands of the deserts after they returned from their campaigns. Finally we have this country overrun with Arabian nomads, the destruction through neglect of their irrigation systems and the death of agriculture due to a change in the character of the people.

So far as recent explorations and examinations have been made there appears to be no fundamental change in the composition or constitution of the soils resulting from this long occupation but the promise is given that the agriculture can be restored with the restoration of the irrigation system upon which the agriculture of the country was originally established.

Spain

We come now to a consideration of the last of the countries selected as illustrating a marked decline in agriculture in historic times, and we will now turn our attention to the consideration of the Moorish provinces of Spain which for 800 years are reputed to have been as productive as it is possible to conceive and which suddenly reverted to a wild and sterile condition after the forces of Ferdinand and Isabella had finally driven the remnants of the Moors back to the northern shores of Africa.

In 711 A.D. the Moors after moving across and occupying the entire northern coast of Africa advanced into Spain and took possession of a great part of the Spanish peninsula. They even entered southern France and occupied for a time Narbona, besides the islands of Sardinia, Corsica, and the Balearic Islands. Eight hundred years later they were finally driven out of Spain.

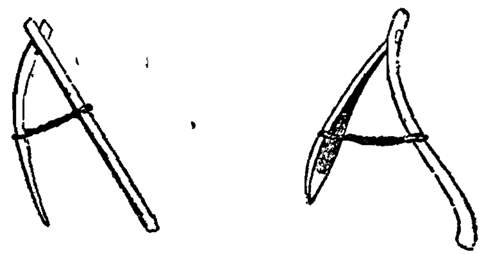


FIG. 22. Two types of the ancient form of hoe. (This is a very different implement from the *modern hoe. It may have been used more as* our mattock is used, to loosen the surface rather than to kill weeds.)

The most spectacular part of this era is, of course, the final struggle between them and Ferdinand and Isabella in the capture of Granada and of the great palace of the Alhambra, as told by Irving in his account of the Alhambra and in his "Conquest of Granada" and as told by Prescott in his "History of Ferdinand and Isabella." That part of Spain occupied by the Moors was a barren desolate waste of desert country when they arrived and has much the same character at the present time. The Moors, however, with indomitable energy and skill converted the barren plains into a garden of delight through their engineering skill in the construction of reservoirs, terraces and canals.

Irving has described the conditions in the province of Granada at the time of the conquest, when the Moors had been driven to their last stronghold in southern Spain:

"This renowned kingdom, situated in the southern part of Spain, and washed on one side by the Mediterranean sea, was traversed in every direction by Sierras or chains of lofty and rugged mountains, naked, rocky, and precipitous, rendering it almost impregnable, but locking up within their sterile embraces deep, rich, and verdant valleys of prodigal fertility.

"In the center of the kingdom lay its capital, the beautiful city of Granada, sheltered, as it were, in the lap of the Sierra Nevada, or Snowy Mountains. Its houses, seventy thousand in number, covered two lofty hills with their declivities, and a deep valley between them, through which flowed the Darro. The streets were narrow, as is usual in Moorish and Arab cities, but there were occasionally small squares and open places. The houses had gardens and interior courts, set out with orange, citron, and pomegranate trees, and refreshed by fountains, so that as the edifices ranged above each other up the sides of the hills, they presented a delightful appearance of mingled grove and city. One of the hills was surmounted by the Alcazaba, a strong fortress, commanding all that part of the city; the other by the Alhambra, a royal palace and warrior castle, capable of containing within its alcazar and towers a garrison of forty thousand men; but possessing also its harem, the voluptuous abode of the Moorish monarchs, laid out with courts and gardens, fountains and baths, and stately halls, decorated in the most costly style of oriental luxury. According to Moorish tradition, the king who built this mighty and magnificent pile, was skilled in the occult sciences, and furnished himself with the necessary funds by means of alchemy. Such was its lavish splendor that even at the present day, the stranger, wandering through its silent courts and deserted halls, gazes with astonishment at gilded ceilings and fretted domes, the brilliancy and beauty of which have survived the vicissitudes of war and the silent dilapidation of ages.

"The city was surrounded by high walls, three leagues in circuit, furnished with twelve gates, and a thousand and thirty towers. Its elevation above the sea, and the neighborhood of the Sierra Nevada crowned with perpetual snows, tempered the fervid rays of summer; so that, while other cities were panting with the sultry and stifling heat of the dog-days, the most salubrious breezes played through the marble halls of Granada.

"The glory of the city, however, was its vega or plain, which spread out to a circumference of thirty-seven leagues, surrounded by lofty mountains, and was proudly compared to the famous plain of Damascus. It was a vast garden of delight, refreshed by numerous fountains, and by the silver windings of the Xenil. The labor and ingenuity of the Moors had diverted the waters of this river into thousands of rills and streams, and diffused them over the whole surface of the plain. Indeed, they had wrought up this happy region to a degree of wonderful prosperity, and took a pride in decorating it, as if it had been a favorite mistress. The hills were clothed with orchards and vineyards, the valleys embroidered with gardens, and the wide plains covered with waving grain. Here were seen in profusion the orange, the citron, the fig, and pomegranate, with great plantations of mulberry trees, from which was produced the finest silk. The vine clambered from tree to tree; the grapes hung in rich clusters about the peasant's cottage, and the groves were rejoiced by the perpetual song of the nightingale. In a word, so beautiful was the earth, so pure the air, and so serene the sky, of this delicious region, that the Moors imagined the paradise of their Prophet to be situated in that part of the heaven which overhung the kingdom of Granada."

Prescott has described conditions as essentially the same and gives two important references, one from a late traveler and one from an early traveler, marking the enormous changes that took place between the time of Moorish occupation and of Spanish occupation.

" But the best mine of the caliphs was in the industry and sobriety of their subjects. The Arabian colonies have been properly classed among the agricultural. Their acquaintance with the science of husbandry is shown in their voluminous treatises on the subject, and in the monuments which they have everywhere left of their peculiar culture. The system of irrigation, which has so long fertilized the south of Spain, was derived from them. They introduced into the Peninsula various tropical plants and vegetables, whose cultivation has departed with them. Sugar, which the modern Spaniards have been obliged to import from foreign nations in large quantities annually for their domestic consumption, until within the last half-century, when they have been supplied by their island of Cuba, constituted one of the principal exports of the Spanish Arabs. The silk manufacture was carried on by them extensively. The Nubian geographer, in the beginning of the twelfth century, enumerates six hundred villages in Jaen as engaged in it, at a time when it was known to the Europeans only from their circuitous traffic with the Greek Empire. This, together with fine fabrics of cotton and woolen, formed the staple of an active commerce with the Levant, and especially with Constantinople, whence they were again diffused, by means of the caravans of the North, over the comparatively barbarous countries of Christendom.

" The population kept pace with this general prosperity of the country. It would appear, from a census instituted at Cordova at the close of the tenth century, that there were at that time in it six hundred temples and two hundred thousand dwelling houses; many of these latter being, probably, mere huts or cabins, and occupied by separate families.

* * * * * * * * * *

" The Arabs exhausted on it (the cultivated *vega,* or plain, in Granada) all their powers of elaborate cultivation. They distributed the waters of the Xenil, which flowed through it, into a thousand channels for its more perfect irrigation. A constant succession of fruits and crops was obtained throughout the year. The products of the most opposite latitudes were transplanted there with success; and the hemp of the north grew luxuriant under the shadow of the vine and the olive. Silk furnished the principal staple of a traffic that was carried on through the ports of Almeria and Malaga."

Comparing this with conditions after the Moors had been expelled, he says:

"The recurrence of seasons of scarcity, and the fluctuation of prices, might suggest a reasonable distrust of the excellence of the husbandry under this reign. The turbulent condition of the country may account for this pretty fairly during the early part of it. Indeed, a neglect of agriculture to the extent implied by these circumstances is wholly irreconcilable with the general tenor of Ferdinand and Isabella's legislation, which evidently relies on this as the mainspring of national prosperity. It is equally repugnant, moreover, to the reports of foreigners, who could best compare the state of the country with that of others at the same period. They extol the fruitfulness of a soil which yielded the products of the most opposite climes; the hills clothed with vineyards and plantations of fruit-trees, much more abundant, it would seem, in the northern regions than at the present day; the valleys and delicious vegas, glowing with the ripe exuberance of southern vegetation; extensive districts, now smitten with the curse of barrenness, where the traveler scarce discerns the vestige of a road or of a human habitation, but which then teemed with all that was requisite to the sustenance of the populous cities in their neighborhood."[1]

[1] "Compare, for example, the accounts of the environs of Toledo and Madrid, the two most considerable cities in Castile, by ancient and modern travellers. One of the most intelligent and recent of the latter, in his journey between these two capitals, remarks, 'There is sometimes a visible track, and sometimes none; most commonly we passed over wide sands. The country between Madrid and Toledo, I need scarcely say, is ill peopled and ill cultivated; for it is all a part of the same arid plain that stretches on every side

Prescott's description of the agricultural life of the Moors in Spain is quite different from our concept of the character of the people from which they sprung and of the character of the main branch of the family in their native habitat up to the present, but the story is sufficient for our purpose as indicating a marvelous development of an arid region by an industrious people, based upon a vast irrigation system, the care of which, after the conquest, was completely abandoned, with the result that the country reverted to a state of desolation. There is no occasion to go further to attempt to describe the struggles, the wars, and the battles with the change of people. There is no need to consider whether the soil deteriorated through those 800 years of occupation. History records the fact that up to the last moments of Moorish occupation the soils were extraordinarily productive. After the curtain falls and they are expelled agriculture dies. The change is immense — it is sudden and dramatic and is worthy of the handling of a Dumas in the suddenness and completeness of the relapse.

We have now completed the consideration of those countries in which agriculture has died. It has been shown that its death was accomplished through a change of population. It has been shown that the opinion of our present engineers of note is that the agriculture of these countries can be built up only through the restoration of a system of irrigation comparable with the

---

around the capital, and which is bounded on this side by the Tagus. The whole of the way to Toledo, I passed through only four inconsiderable villages, and saw two others at a distance. A great part of the land is uncultivated, covered with furze and aromatic plants; but here and there some corn land is to be seen.' (Inglis; "Spain in 1830," vol. 1, p. 366.) What a contrast does all this present to the language of the Italians, Navagiero and Marineo, in whose time the country around Toledo 'surpassed all other districts of Spain in the excellence and fruitfulness of the soil;' which, 'skillfully irrigated by the waters of the Tagus, and minutely cultivated, furnished every variety of fruit and vegetable produce to the neighboring city;' while, instead of the sunburnt plains around Madrid, it is described as situated 'in the bosom of a fair country, with an ample territory, yielding rich harvests of corn and wine, and all *other aliments of life.*' "*Cosas memorables,*" *fol. 12,* 13. — Viaggio, fol. 7, 8."

system that prevailed at the time of their greatest prosperity. So far as these countries are concerned there is nothing to fear that their soils have been necessarily depleted through intelligent and constant occupation through countless centuries.

We come now to consider the case of the second set of old countries, those in which there has been no sharp break in the agriculture and we want to examine the conditions to see what is the reason that agriculture has survived and too, if we can, if the long centuries of crop production have decreased or have increased the productive capacity of the soils.

To start out with, it is impossible to get reliable statistics as to the yield per acre in the olden times. There are marvelous stories such as the Arabian tale that at the time of the Garden of Eden the grain of wheat was as large as a roc's egg. There are marvelous tales of enormous yields in prehistoric times. These can not be checked or verified with any definite information.

On the other hand we have the present yields of these older countries where the soils have been occupied for agricultural purposes for thousands of years and we have the yields for our own country which has been occupied for agricultural purposes for not over two or three hundred years. To come down to hard facts, it seems perfectly logical that we should compare the present yields in these old countries with the yields of new countries in order to judge of the effect of long-time cultivation of the soils. If there was some miraculous condition that gave large yields to the early peoples of the world the conditions in this country would probably have favored an equally high yield per acre, but as we have no evidence of such unusual conditions we are quite justified in believing that the yield in the new and the old countries would be similar except for the influence of the people either in decreasing or increasing the yields of soils during these thousands of years that the older countries have been under occupation. At any rate before we take up the consideration of the agriculture of the second group of old countries to determine what effect the long occupation of the land has had, it is proper for us to give at this time a yardstick by which we may measure the relative productivity of soils.

It is a well-established fact that the yield of cereal crops per acre increases near the northern limit of crop production. We have, therefore, prepared a table showing the yield per acre of wheat of our states from north to south, one extending from Maine to Georgia and the other extending from Michigan to Alabama in the ten years, 1911 to 1920, in which the average yield of wheat in the United States is estimated at 14.6 bushels. We have also given the yields per acre in a north and south line in Europe for a five-year average (1910 to 1914) from the United Kingdom to Italy.

Yield of Wheat Per Acre

10-Year Average in the United States (1911–1920)

	Bushels		*Bushels*
Maine	23.0	Michigan	16.8
New York	20.6	Indiana	15.4
Pennsylvania	17.3	Kentucky	12.0
Maryland	16.0	Tennessee	10.8
Virginia	12.8	Alabama	10.6
North Carolina	10.1		
South Carolina	10.9		
Georgia	10.7		

Average for the United States .... 14.6 bushels

5-Year Average in Europe (1910–1914)

	Bushels		*Bushels*
United Kingdom	32.4	France	19.1
Germany	31.7	Italy	15.6

We have on the authority of several reliable writers an estimate that the present yield of wheat in China is about 25 bushels per acre and in Japan about 17 bushels per acre, while in Roumania the present yield is given at about 16 bushels.

It will be seen from a comparison of these states and countries that from the present showing the evidence seems to indicate that at least the newer soils of our country are not above the yields of the older countries of the world.

China

It is supposed that in the original migration of man from southwestern Asia there was a migration through central Asia possibly when this country was much more humid and productive than under present climatic conditions and that as a result possibly of changing climatic conditions the people were forced eastward and came down through the "Jade Gate" about 10,000 B.C. reaching the Hwangho Basin about 2600 B.C. This appears to be the date of the earliest written record of the Chinese but these records indicate a great development of culture and of organized society as the first Emperor Huangti of that period established 10,000 states and gave directions for laborers and workmen to construct the cities for the states and for an organized system of dividing the lands for fostering agricultural development. These earliest records of the Chinese suggest a previous high state of society extending back possibly to the year 10,000 B.C.

The history of China differs materially from the history of the countries which have been described. Within historic times and probably long ago in the dawn of history the Chinese have been peculiarly free from foreign invasion except through the gradual coalescence of surrounding people into their organized life. There have of course through the past been invasions, revolts, and internal changes but the people and the culture have succeeded in maintaining supremacy and the Chinese as a race have never been overthrown and driven out as in the case of Mesopotamia, Syria, and Asia Minor. The one people have been able to develop their agriculture and their society with comparatively little foreign disturbance through the ages.

King visited the country, ...

after twenty and perhaps thirty or even forty centuries for their soils to be made to produce sufficiently for the maintenance of such dense populations as are now living in these three countries (China, Korea and Japan)." "It should be observed," says King, "that the United States as yet is a nation of but few people widely scattered over a broad virgin land with more than twenty acres to the support of every man, woman, and child, while the people whose practices are to be considered are toiling in fields tilled more than 3,000 years and who have barely one acre per capita, more than half of which is uncultivatable mountain land. . . . It is well nigh impossible by word or map to convey an adequate idea of the magnitude of the systems of canalization and delta and other low land reclamation or of the extent of surface fitting of fields which have been effected in China, Korea, and Japan through the many centuries and which are still in progress." In another place he estimates the canals of China to be at least 200,000 miles long which is nearly equal to the railroad mileage of the United States.

The other book is the "Economic History of China with Special Reference to Agriculture" by Mabel Ping-Hua-Lee, published in 1921. This gives an exceedingly interesting and valuable summary with reference to the original Chinese text of each dynasty from 2698 B.C. to the present.

It appears that about half of the China of to-day is too rough and mountainous for agricultural use. The rainfall in south China at the present time is about 80 inches per annum, most of which falls in the summer or growing season. The rainfall in the Shantung province is given at about 24 inches at least 17 inches of which falls principally in July and August. There are a number of large rivers in China. The Hwangho carries at low stage past the city of Tsinan 4,000 cubic yards of water per second and at least three times as much more at flood stage.

The Emperor Yao, the beginning of whose reign was 2357 B.C.,

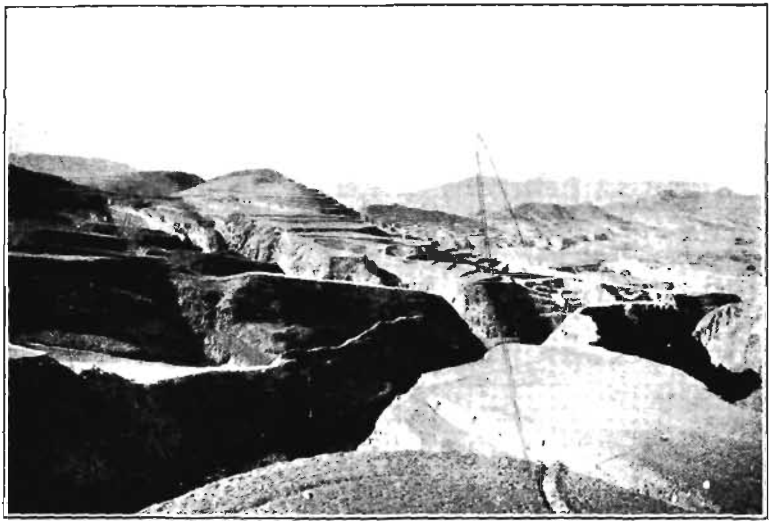


PLATE III

This gives some idea of the immense amount of work involved in the regulation of the land surface in parts of both China and Japan. Mentioned by King as one of the characteristic features of the agriculture of these countries (photograph by Bailey Willis).

Plate III

This gives some idea of the immense amount of work involved in the regulation of the land surface in parts of both China and Japan. Mentioned by King as one of the characteristic features of the agriculture of these countries (photograph by Bailey Willis).

appointed the celebrated engineer Yu as Minister of Public Works to control the floods, to drain the low lands, and to classify the soils of the different provinces. At the time of the appointment of Yu the whole country was in a state of flood which for a time disorganized society. The Minister Yu not only began the control of the river floods but organized drainage plans for the vast deltas at the mouths of the rivers. The emperors of China have always given careful thought to agriculture and the great engineering work begun under Yu has been continued incessantly throughout the ages until the present time as shown in the Chinese records. In spite of these long centuries of flood control, in 1877 A.D. the Hwangho river broke through its banks and inundated a vast area bringing death to a million people. Again in 1898 A.D. 1500 villages to the north of Tsinan and a much larger area to the southwest were destroyed by floods. Such has been the mighty work of the Chinese and such the awful forces of nature which in the centuries they have been unable to protect themselves against.

The history of the agriculture of China since the earliest days has been a desperate struggle against the floods from the rivers and against drought which in some cases has spread over a period of seven consecutive years. These have been the enemies of China, these the things they have fought against. The nations to the south seem to have been able to cope with nature. Asia Minor and Mesopotamia have seemed to be able to control floodwaters and to alleviate the droughts on their irrigated fields, but the Chinese with all their engineering skill, with the immensity of their engineering works, have been subjected first to periods of disastrous floods and then to periods of excessive droughts. The history of China opens with a great flood and within recent years there have been two other notable floods. Their early history also shows disastrous droughts — it was only a few years ago that, it is estimated 15,000,000 died in China as a result of a disastrous drought.

After the opening of the great drama in 2698 B.C. and extending to 2599 a thousand years passed without notable mention of agricultural conditions. The curtain rises again in the beginning of the Chow dynasty in 1122 B.C. We have here described the duty of the First Minister of the Land Department in great detail in which he was required to see that the land was properly distributed between crops and pastures, to see that land suitable for culture was kept in crops, to teach the people soil adaptation, the care of tools, and to see that the distribution of land was equable, to spur the people to a system of intensive cultivation and the greatest possible use of the land.

All through the ages of Chinese history there are records of floods followed by famine, of disastrous droughts followed by famine, of insect pests that have destroyed the crops of entire provinces, and of plagues, but through it all there appears to have been a serious study of agriculture by the emperors, of every attempt being made to alleviate suffering, an indomitable purpose after the great disasters to teach the people the lessons to be learned, watchful always of the land tenure, or improved methods of cultivation, of the use of every kind of waste that could be put back on the land, of the use of their composts, manures and city refuses, the grading of the surface into level fields and terraces running up to a thousand feet or more on the mountain slopes, of the canalization and drainage of their lands, the distribution of seeds and of plants, the prevention of erosion and the care of the increasing hundreds of thousands of population.

The result of this stupendous effort as shown by the statement King makes of his recent visit shows that they have not yet succeeded in controlling the forces of nature for the Chinese people are today having the disastrous floods and the same disastrous droughts that they have been having through all the ages of historic times.

But they have accomplished this. They have come down through these centuries of occupation and King tells us that the average yield of wheat in China to-day is 25 bushels per acre which is considerably more than the average yield of wheat in any of the states of the United States. The average yield of wheat in the Shantung province is 42 bushels per acre. He saw fields that gave 95.6 bushels and 116 bushels per acre. He speaks of corn as yielding from 60 to 68½ bushels per acre, of potatoes yielding 286 bushels, of sweet potatoes 440 bushels per acre, of millet from 48 to 96 bushels of seed per acre, of barley as yielding 26 bushels per acre, of dry land rice yielding 20 to 26 bushels per acre, of water rice for China as a whole 42 bushels per acre, while individual fields that he visited gave yields of from 33 to 80 bushels per acre. He speaks of pink clover as yielding 20 tons of green product per acre. It is usual for two or three crops to be grown annually on the same land for which King reports that it is not unusual for a Chinese farmer to make from $160 to over $200 per acre in American money.

It would appear from these records and observations that the productivity of these soils which have been under agricultural occupation for all these centuries by a people who have come through without wars of extermination has been maintained as to yields while on the evidence of the chemical composition of the soil they compare very favorably with the newer soils of the United States. It is not for us here to discuss the density of population; whether China has sufficient land to provide enough for her people. It is not for us to consider the agricultural methods of the Chinese. We have only mentioned the floods and the droughts as illustrating the natural conditions they have had to meet but the one thing we were to examine was as to whether the soils of China through all of these ages of use have or have not shown deterioration from such use and the records appear to show that there has been no deterioration.

China has been left to work out her own problems with agriculture recognized as the most important problem of the nation. China has never had the experience of Asia Minor or of Mesopotamia where by a change of people the very basis of agriculture, that is the irrigation system, has been completely destroyed.

Japan

Japan has had a history somewhat similar to that of the Chinese in that there have been no external wars of conquest to disturb the people or to interfere with the race in the development of their agriculture. The Japanese claim a history of about 6,000 years during which time the same race and class of people have been in possession of the country. We are in a position now to understand the words recently spoken by one of the professors in the University of Tokyo. He was asked if during all of these ages of occupation they found any evidence of deterioration in their soils and he replied that on the contrary, they valued their oldest lands the most as they were better regulated, were under better control and, having been passed down for ages through the same families, they were thoroughly understood. He further said that in Japan the worst injury that could be inflicted upon an enemy was to put him on virgin land.

The control and regulation of the land in this sense means the leveling of the fields, drainage and irrigation as required, the building of terraces, the adaptation of crops, the rotation of crops, the utilization of waste material, and of all those operations which have been found through the experience of ages to be best adapted to each type of soil and to each locality.

Japan with her dense population has a comparatively small area in crops. It is estimated but 14 per cent of the area of Japan is arable land, there being 63 per cent in forest, and 11 per cent that is possible of reclamation. Of the total area of Japan 12 per cent is not susceptible of use for agriculture or forestry, being utilized for cities, town lots and roads, and including among other areas the rough mountain-tops not in forest. So far as history reveals Japan has not had the constant struggle with nature in floods and droughts that China has had to face.

The average annual yield of wheat for Japan for the years 1909 to 1913 was 21.4 bushels per acre. Professor King states that on the plains of Tokyo the yield is between 38.5 and 41.3

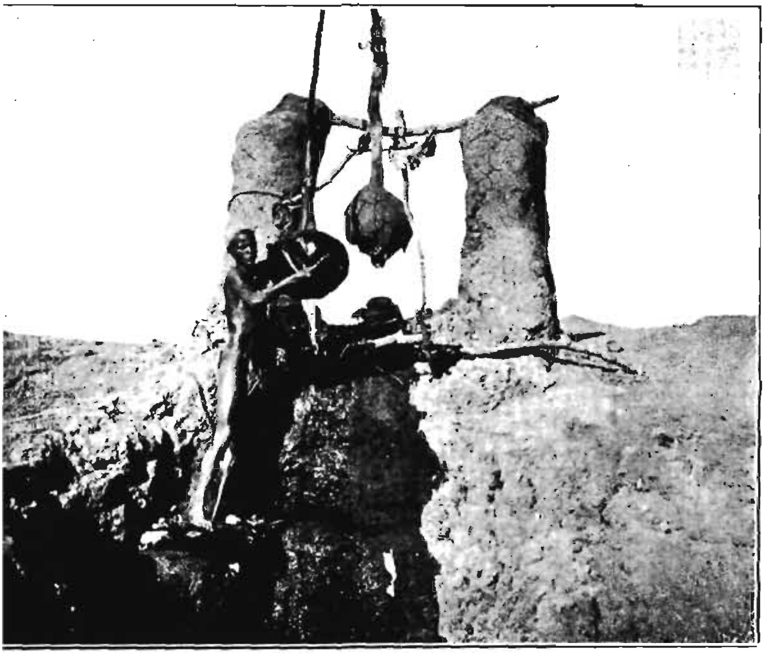


Plate IV

rrigating fields from wells or fields above river level. From a recent photograph, showing that the method has not changed materially from the earliest times. Compare figure 23.

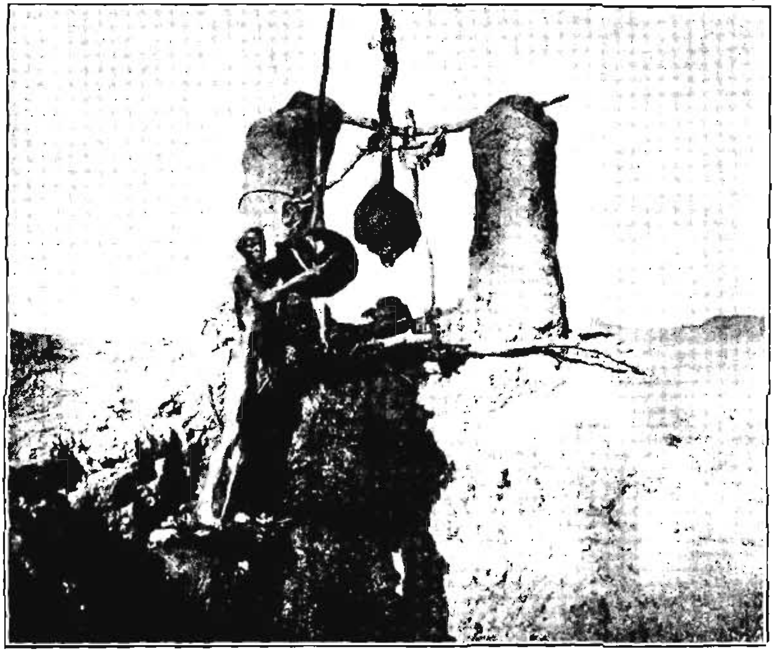


PLATE IV

Irrigating fields from wells or fields above river level. From a recent photograph, showing that the method has not changed materially from the earliest times. Compare figure 23.

bushels per acre, with potatoes yielding from 352 to 361 bushels per acre. The record of the present yields of Japan as compared with the present yields of the newer soils of the United States gives no evidence of deterioration through the long centuries of continued use.

Egypt

The history of Egypt is one of peculiar charm. Egypt forms the gateway between Asia and Africa but beyond Egypt lie the deserts and wild places of the earth which have given her a

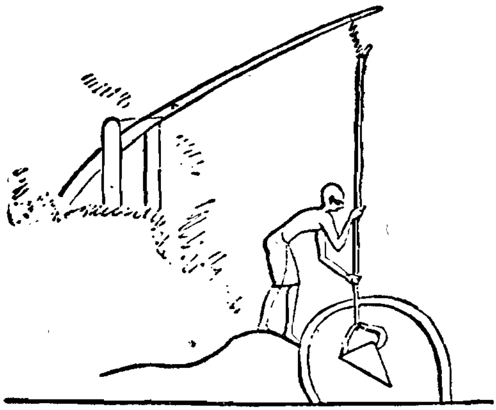


FIG. 23. Irrigating fields from wells or fields above river level. From an Egyptian tomb. (Here we have the forerunner of the wellsweep, which was not an unfamiliar sight to the last generation in our own country. Think of the labor involved in irrigating any considerable area in this way!)

protection of locality that Mesopotamia and Asia Minor did not have. In other words while the nations of the old world cast covetous eyes on the fertile lands of Egypt there was nothing beyond to induce them to pass through the territory on any desire of conquest beyond her realm. It was a country isolated as it were with an impenetrable background which in a measure was a defensive wall shutting her off from the rest of the continent of Africa. The line of travel and of conquest was either into Egypt itself or along the northern shore of Africa where the trade routes passed in that period. The country formed a vast delta plain of the river Nile and on either side of the delta there was desert.

The history of Egypt is too well known to require any detailed description in this place even if space would permit. It is thoroughly covered by all of the old historians who tell of the invasions by the Persians, by the fierce Assyrians, by the nomadic tribes of Arabia, of the conquests by the Greeks and by the Romans, of its annexation by the Turks, and of its later occupation by the French and still more recently by the English.

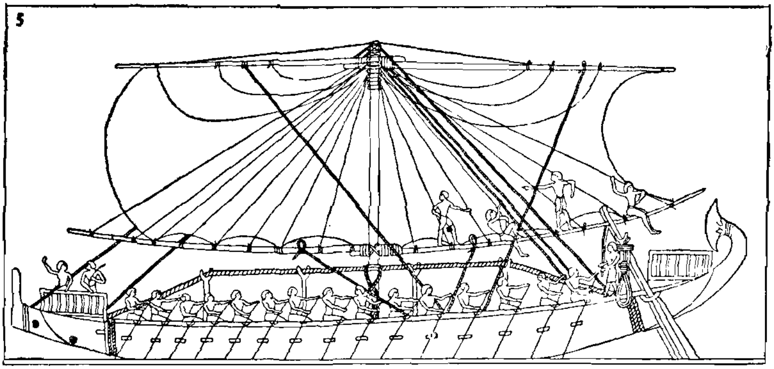


FIG. 24. An Egyptian merchant ship for sea trade. From one of the early tombs. (Commerce was slow and uncertain when it depended alone on man and the fickle winds for motive power. Yet the art of ship building and of navigation had made considerable advances in this period.)

These conquests, however, were aimed at the government. The occupation was of a political nature and through it all since history began the Egyptian people have occupied their lands without much consideration or without much knowledge as to who the rulers might temporarily be. Even the reigning families have succumbed to domination but not to entire extinction. With all her reverses there has been a continual occupation of the land by Egyptian people.

Egypt is a country of very low rainfall and the agriculture has been entirely dependent upon the regular floods of the river Nile.

The Nile rises in three different parts of an exceedingly wild and mountainous country that has not even yet been thoroughly explored. But somewhere back in these hidden lands almost as regular as clockwork the river Nile starts in a state of flood approximately on the 1st of August and ends approximately on the 30th of November. Throughout all history this river has flooded and receded once each year and no more.

Until the year 1820 this periodic flooding had been almost the sole support of agriculture. The floodwaters were caught in basins about the middle of August and the discharge of the waters from these basins began about the first of October giving the opportunity of producing one crop each year. Canals were dug even in the earliest times to help distribute the waters over larger areas. At the present time there are about 1,750,000 acres that are still irrigated by this old natural system. Since 1820 the delta and middle Egypt have been able through a system of canals to obtain water from the river throughout the year and at the present time about 4,000,000 acres are under cultivation through a perennial system of irrigation that permits two or three crops to be harvested on the same land each year.

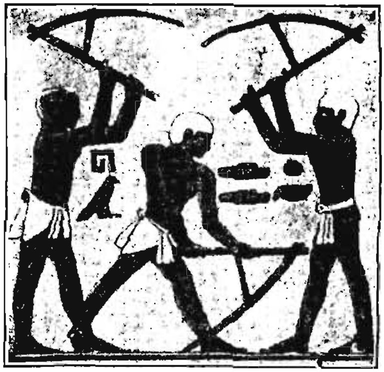


FIG. 25. The ancient form of hoe as it was used. (Delta soils are commonly free from gravel and the fine-textured soils of the Nile and Euphrates Valleys were much more amenable to an implement of this sort than stony upland soil would be.)

In ancient times there was no necessity for the protection against erratic floods such as were liable to occur in Asia Minor, Mesopotamia, or China. Therefore there were no extensive engineering works protecting the agriculture of Egypt as was necessary in those other countries. The agriculture of Egypt was therefore less vulnerable because it was such a simple system that it could not be destroyed.

While the river Nile is so regular in its floods that it could almost be used as a measure of time, there have been years when the floods have not arrived and famine on a huge scale has devastated the country. There have been other times when the

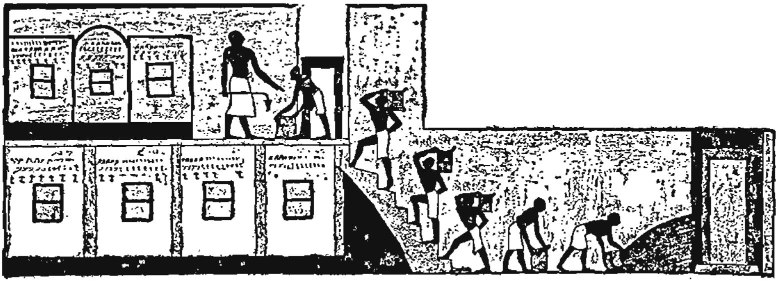


FIG. 26. Measuring and storing wheat in granaries. From an Egyptian tomb. (One marvels at the elaborate provision made in this remote period for protecting the grain until such time as it should be marketed. Everywhere human labor takes the place of machinery.)

flood was so excessive, beyond all experience of living men, that destruction has come. So that agriculture has from time to time suffered periods of drought and of excessive floods which have been commented on by historians as conditions so rare as to be worthy of record.

In Roman times Egypt with its stable system of irrigation was looked upon as the granary of the world and even before the Roman occupation the command of commerce of the Mediterranean was considered a vital factor in the life of the countries of that period.

It is impossible to tell what the yields were in those early days. As articles of commerce they had wheat, barley and maize, rice, millet, dates, oranges, citron, figs, grapes, apricots, and peaches. The present yield of wheat as an average for the years 1909 to 1913 is given as 25.4 bushels per acre.

It is the common belief that the Nile has fertilized these soils with the sediment it brings down and has so maintained the productivity of the Egyptian soils through long years of occupation. The yield of wheat of China is given as about the same as the yield of Egypt but China is much farther north where wheat would be expected to produce larger yields. In none of the

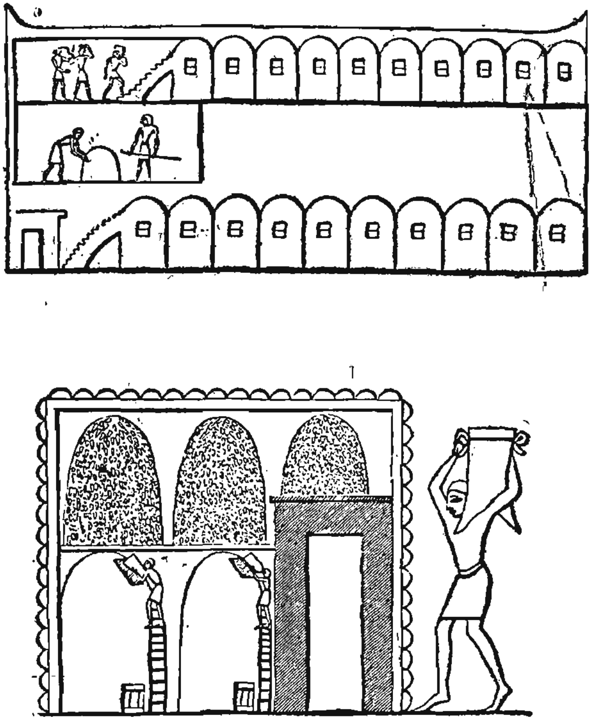


FIG. 27. Two other forms of granaries. From Egyptian tombs. (Rooms for housing the grain, apparently vaulted. Granary showing how the grain was put in, and that the doors at the base of the sketch were intended for taking it out.)

countries that have been or will be studied are the conditions parallel to those of Egypt with the regular ebb and flow of a mighty river that waters the ground and leaves it every year in perfect condition for a crop. There is no other country in the world that has enjoyed such a natural system of irrigation so regular and orderly as has Egypt. All we can say is that the present yields indicate when compared with the yields of wheat in newer countries of the world that the soils of Egypt have not deteriorated through occupation of untold centuries.

All of the countries we have heretofore considered have had irrigation systems, methods for the control of storm waters, and methods for the alleviation of drought. Egypt's was a natural system of irrigation, the others have all been artificial and have been vulnerable to attack.

Greece and Rome

We come now to the consideration of the soils of Greece and of the early Roman provinces of Italy where irrigation has never been systematically carried on nor depended upon in any systematic way to fortify and to protect cultivated fields.

The history of organized society in Greece and in Rome is not so easy to trace back through the ages as in the case of the countries we have already spoken of. Greece and Rome although occupying areas of relatively low rainfall had no great engineering feats to perform in the protection against floodwaters or in the irrigation of their lands. They were, therefore, not tied down to their lands as was the case in countries where natural or artificial irrigation was the basis of agriculture. Their people were not nomads but on the other hand they were not the settled people of irrigated countries where constant vigilance must be maintained to guard against the forces of nature. They were free to move with only the loss of an annual crop without fear of losing vast engineering works.

The beginning of organized society in both Greece and Rome is mythical in the extreme with stories of gods and goddesses who were supposed to have had direct personal contact with the affairs of the people. The city of Rome is supposed to have been founded about 753 B.C. and there is a mythical epoch of the Kings of Rome extending from 753 B.C. to 510 B.C., but Romulus who is supposed to have been the founder of Rome is said to have appointed one hundred senators which would indicate that in his time the city must have been of fair size.

Carthage on the north shore of Africa is supposed to have been founded in 800 B.C. but we may put this fact aside for the present for we hear very little of Carthage until 348 B.C. when the Romans made the first treaty of commerce with Carthage.

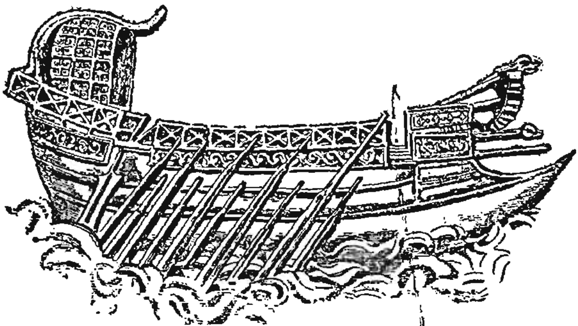


FIG. 28. A Roman bireme, a merchant vessel of the early Roman period. (This vessel seems even less adequate for its purpose than the one shown in figure 24.)

Greece developed much earlier than Rome and long before the height of the Roman influence Greece had passed its high point of development and had fallen to a mere vassal state. The Greeks and the Romans probably belonged to the great Aryan family, and the Pelasgian branch of the family is supposed to have divided into the Italians and the Hellenes. The earliest historical information shows the Hellenes to have been divided into various tribes, the Achaeans being most prominent during Heroic or mythical times and were used by Homer to denote the entire race, and in historic times the Dorians and Ionians. Some historians believe the Dorians forced their way over the Hellespont into the mountainous region of northern Greece as shepherds and tillers of the land while other bands including the Ionians descended from the highlands of Phrygia and occupied the coast and islands of the archipelago developing into sea-faring men. Other legends suggest that they came from Egypt.

Down to about 1000 B.C. therefore everything is mythical and extravagant in the extreme but this one fact comes out in the picture after the curtain rises on the known history of Greece, namely that the country was settled by different bands of people who were suspicious and antagonistic to each other, jealous of each other's progress and only in cases of great emergency would they come together and help in the national defense. The intense rivalry between Sparta and Athens is a case in point, always jealous of each other, always fighting each other on the least provocation and reluctant to help each other even in cases of dire need as when the country was invaded by the Persian hosts.

We have historic data beginning with 820 B.C. in the Constitution and Laws of Lycurgus. In 776 B.C. there was the first Olympiad, in 734 B.C. the foundation of Syracuse, in 743 B.C. to 724 B.C. the First Messenian War, in 645 to 628 B.C. the Second Messenian War. Then came the famous Constitution and Laws of Solon about 594 B.C. In 560 B.C. Sparta was in the ascendence. In 500 B.C. the first of the four great Persian Wars against Greece began in which took place the famous battles of Marathon and Thermopylae and the naval battle of Salamis. In 477 B.C. the command of the army was transferred from Sparta to Athens. After further wars between Sparta and Athens in 445 B.C. a thirty-year truce was arranged. This was the most brilliant epoch in the history of Athens under the leadership of Pericles. That general period gave rise to Aeschylus, Sophocles, Euripides, Aristophanes, Herodotus, Thucydides, Socrates, Protagoras and Demosthenes.

This was followed by the Peloponnesian War, the war of Athens against Syracuse, the Decelean War and finally in 404 B.C. the surrender of Athens. Three years later there is the retreat of the Ten Thousand under Xenophon. This was followed by an offensive war of Sparta against Persia. Then came the Corinthian War, the war between Thebes and Sparta, the rise of Macedonia under Philip and finally there comes on the scene Alexander the Great — 336 to 323 B.C. Alexander carried on war against Persia; there is his pursuit of Darius, his expedition through India and his death in Babylon which he had destined for the capital of the new empire. In 146 B.C. Corinth was captured and destroyed and Greece became a part of the Roman Empire.

In regard to Italy it is uncertain as to what part was settled from the north and how much of the southern part was settled by the Greeks, but it is certain that when Rome was established and for some time thereafter the northern part of Italy was divided into states and kingdoms that were jealous and fearful of the growing power of Rome. From 616 to 578 B.C. there are records of wars with the Sabines, the Latins and the Etruscans until finally Rome joined the Latin League. The subjugation of Italy proper occupied much of the attention of Rome from 510 to 264 B.C. The first Agrarian laws were passed in 486 B.C. in an endeavor to reconcile the differences between the Patricians and the Plebeians.

Asia Minor, Mesopotamia and Syria had natural agencies to combat in the development of their agricultural life and they had dreadful wars from the outside to defend themselves in as well as they might. Rome on the other hand had an insidious conflict passing through all her history, through her greatest power and this was the cause of her final collapse, the conflict between the Patricians and the Plebeians. These conflicts at home were more appalling and more disastrous to the Roman generals than were their conflicts in their campaigns of subjugation.

In 463 B.C. the plague was in Rome and throughout the Roman states. In 390 B.C. Rome was destroyed by the Gauls. In 367 B.C. the Licinian laws were passed in the interest of the Plebeians and the poorer classes in which a limit was placed on the land holdings by one person. In 367 B.C. to 349 B.C. war was carried on against the Gauls who had permanently settled in upper Italy. In 348 B.C. it became necessary to arrange the first treaty of commerce with Carthage. From 342 to 262 B.C. all of Italy to the Rubicon was finally subjugated by Rome. At this time Rome had organized and was recognized as the first land power but Carthage was the first sea power. From 264 to 241 B.C. occurred the First Punic War. In 225 B.C. the Gauls were again driven out of northern Italy. In 218 to 201 B.C. the Second Punic War started with the invasion of Italy by Hannibal from Spain. From 214 to 205 B.C. occurred the First Macedonian War when Syracuse fell to the Romans, also the wars with Spain as a result of which Spain became a Roman province. In 200 to 197 B.C. occurred the Second Macedonian War. Then the war was carried into Syria. In 171 to 167 B.C. occurred the Third Macedonian War and the destruction of that monarchy.

In 149 to 146 B.C. occurred the Third Punic War which resulted in the capture and destruction of Carthage. The city was burned, the fire lasting seventeen days. The inhabitants who remained were sold into slavery and northern Africa became a Roman province. In 146 B.C. Corinth was destroyed by the Romans and Greece soon after became a Roman province. This establishment of the almost universal power of Rome was followed by great civil disturbances. In 113 to 101 B.C. wars were carried on against the Germanic and Celtic tribes to the north. In 84 to 81 B.C. war was carried into Asia Minor and in 78 to 67 B.C. war was carried on against the pirates of the Mediterranean Coast to clear the seas for Roman commerce.

In 63 to 61 B.C. occurred the occupation of Syria and the capture of Jerusalem and in 59 B.C. Julius Caesar comes on to the scene as consul. This was followed by the conquest of Gaul and the campaigns in northern Europe. This was followed by civil war and then by the Alexandrian War and then another war in Asia Minor, the war in Africa and the death of Caesar in 44 B.C.

This was followed by wars in Greece and in Egypt with Cleopatra having a leading rôle. In 31 to 14 B.C. was the highest development of Roman literature and Roman power. Then came the beginning of the Christian Era. In 54 to 68 A.D. Nero occupies the stage. In 410 A.D. Alaric captured and sacked Rome. In 476 A.D. occurred the fall of the Roman Empire.

PLATE V

In the second Punic War Hannibal used elephants to demoralize the Roman Legions. Contrast this with the battlefront of our modern armies.

Before the final destruction of the Roman Empire the period of 1,500 years of Dark Ages descended upon the earth, so dark and impenetrable that all of the learning of the Greeks and Romans was forgotten, all society was upset, and all progress was stopped. Were it not for a few writings of the Greeks and Romans which were accidently preserved in dark corners during this dark period the world to-day might have lost all trace of the Greek and Roman civilization.

To show how completely knowledge had passed out of the minds of people contrast the statements made by Pliny on the form of the earth with the persecution and indignities heaped upon Columbus in 1492 A.D. when he was vainly endeavoring to prove to the kings and learned men of his time that the earth was round and not flat as was then believed. Pliny's great work on natural history is one of the works that was preserved during this dreadful dark period in the world's history. Pliny was killed in trying to save people after the destruction of Herculaneum and Pompeii by the eruption of Vesuvius in 73 or 79 A.D.

Pliny's work on natural history has been translated by Bostock and Riley from which translation the following statement is made; " that it," the world, " has the form of a perfect globe we learn from the name which has been uniformly given to it as well as from other natural arguments for not only does a figure of this kind return everywhere into itself and sustain itself, also including itself, requiring no adjustments, not sensible of either end or beginning in any of its parts, and is best fitted for that motion, with which, as will appear hereafter, it is continually turning round; but still more, because we observe it, by the evidence of the sight, to be, in every part, convex and central, which could not be the case were it of any other figure. . . . The rising and the setting of the sun clearly prove, that this globe is carried around in the space of 24 hours, in an eternal and never ceasing circuit, and with incredible swiftness." Again, " everyone agrees that it has the most perfect figure. We always speak of the ball of the earth, and we admit it to be a globe bounded by the poles. It has not indeed the form of an absolute sphere, from the number of lofty mountains and flat plains; but if the termination of the lines be bounded by a curve, this would compose a perfect sphere. And this we learn from arguments drawn from the nature of things, although not from the same considerations which we made use of with respect to the heavens. For in these the hollow convexity everywhere bends on itself and leans upon the earth as its center. Whereas the earth rises up solid and dense like something that swells up and is protruded outwards. The heavens bend towards the center, while the earth goes from the center, the continual rolling of the heavens about it forcing its immense globe into the form of the sphere. On this point there is a great contest between the learned and the vulgar. We maintain, that there are men dispersed over every part of the earth, that they stand with their feet turned toward each other, that the vault of the heavens appears alike to all of them and that they, all of them, appear to tread equally on the middle of the earth. If anyone should ask, why those situated opposite to us do not fall, we directly ask in return whether those on the opposite side do not wonder why we do not fall. But I may make the remark that will appear plausible to the most unlearned, that if the earth were of the figure of an unequal globe like the seed of the pine still it may be inhabited in every part."

There have been preserved to us through the Dark Ages a few works written by the Greek and Roman philosophers which together make quite a voluminous literature on the subject of agriculture extending over a period of about one thousand years between the writings of Hesiod in the year 1000 B.C. and the writings of Pliny in the years shortly before his death in 73 or 79 A.D. No words of ours can as adequately describe the conditions, the soils and the methods during that period of Greek and Roman literature as can the people who were living and writing at that time. It is so important to get clearly before us the facts that even at the risk of appearing to quote too much we will give a full description of the agriculture of the period in the words, as nearly as they can be translated, of the writers and philosophers of that time. It seems desirable to give these very exhaustive extracts before we give our own opinion of the agriculture and the yields of that time as compared with the present. The extracts from Pliny are taken from the translation of his "Natural History" by Bostock and Riley.

Much of this history of agriculture, as in all the writings of those days, is mixed with mythology, the influence of the gods and the influence of the heavenly bodies. Many of the tales are grossly extravagant and facts are evidently distorted, especially where the writers drew their facts from countries that they had not themselves seen. Pliny, the latest of these early writers, can not get away from the supernatural and in one place says, "The only occasion on which there ever was a prodigy connected with grain, at least that I am aware of, was in the consulship of P. Aelius and Cneius Cornelius, the year in which Hannibal was vanquished; on that occasion we find it stated, corn was seen growing upon trees."

Again he makes a statement so grossly extravagant that it would be fit for a place in some of the tales of Baron Munchausen:

"There is a city of Africa, situated in the midst of the sands as you journey towards the Syrtes and Great Leptis, Tacape by name. The soil there, which is always well-watered, enjoys a degree of fertility quite marvellous. Through this spot, which extends about three miles each way, a spring of water flows — in great abundance, it is true — but still, it is only at certain hours that its waters are distributed among the inhabitants. Here, beneath a palm of enormous size, grows the olive, beneath the olive the fig, beneath the fig, again, the pomegranate, beneath the pomegranate the vine, and beneath the vine we find sown, first wheat, then the leguminous plants, and after them garden herbs — all in the same year, and all growing beneath another's shade. Four cubits square of this same ground — the cubit being measured with the fingers contracted and not extended — sell at the rate of four denarii. But what is more surprising than all, is the fact that here the vine bears twice, and that there are two vintages in the year. Indeed, if the fertility of the soil were not distributed in this way among a multitude of productions, each crop would perish from its own exuberance: as it is, there is no part of the year that there is not some crop or other being gathered in; and yet, it is a well-known fact, that the people do nothing at all to promote this fruitfulness."

But through all the works of these ancient writers are words of wisdom and principles of agriculture that are as safe guides to-day as when they were enunciated two or three thousand years ago. There is little in our practice to-day that was not known and not taught in that period and while we have explanations and reasons for things they had the essential facts which we are still striving to understand and improve upon through modern scientific research.

The question of the maintenance of soil productivity for the support of the increasing population of the world was debated in Athens some 2500 years ago, was debated in Rome at a somewhat later date, and is being debated in Washington at the present time. They were asking then the same questions that are being asked in the present day — do soils wear out with constant use and is there a limit to the productive capacity of soils for the needs of increasing populations? Cato answered the question very emphatically by saying, no, the soil does not die as man dies but that the soil responds very little to the shiftless and unintelligent care of ignorant people.

Columella said some two thousand years ago something that has a direct application at the present time:

"The Magnates of the state are in the habit of complaining of the sterility of the land, or of the unsettled state of the weather, which has now for a long time exerted an unfavorable influence on the growth of agricultural produce; others are of the opinion that the soil has been exhausted by the overproductiveness of former years. But no one, gifted with common sense, will ever permit himself to be persuaded that our earth has grown old, as man grows old. The sterility of our fields is to be imputed to our own doings, because we hand over the cultivation of them to the unreasoning management of ignorant and unskillful slaves."

Pliny attributes the decline of Roman agriculture to the growth of cities, to the ease and luxury of city life, the glamour and enervating effects of city living. He contended that large tracts of farming land owned by city men and left to the care of underlings and slaves would eventually ruin the nation and the empire. He quotes the words of Manius Curius after his triumphs and the addition of an immense extent of territory to the Roman Empire as follows, " a man must be looked upon as a dangerous citizen for whom seven jugera of land are not enough," such being the amount of land that had been allotted to the people after the expulsion of the kings. Pliny then goes on to say:

" What then was the cause of a fertility so remarkable as this (when seven jugera of land shall be sufficient for one man)? The fact, we have every reason to believe, that in those days the lands were tilled by the hands of generals, even the soil exulting beneath a plowshare crowned with wreaths of laurel, and guided by a husbandman graced with triumphs: whether it is that they tended the seed with the same care that they had displayed in the conduct of wars and manifested the same diligent attention to the management of their fields that they had done in the arrangement of the camp, or whether it is that under the hand of honest men everything prospers all the better, from being attended to with scrupulous exactness. The honors awarded to Seranus found him engaged in sowing his fields, a circumstance to which he owes his surname. Cincinnatus was plowing his four jugera of land upon Vaticanian Hill — the same that are still known as the Quintian Meadows, when the messenger brought him the dictatorship — finding him, the tradition says, stripped to the work and his face begrimed with dust. ' Put on your clothes,' said he, ' that I may deliver to you the mandates of the senate and the people of Rome.' In those days these messengers bore the name of viator or wayfarer, from the circumstances that their usual employment was to fetch the senators and generals from their fields.

" But at the present day these same lands are tilled by slaves whose legs are in chains, and by the hands of malefactors and men with a branded face! And yet the earth is not deaf to our adjurations when we address her by the name of 'parent' and say that she receives our homage in being tilled by hands such as these, as though, forsooth, we ought not to believe that she is reluctant and indignant in being tended in such a manner as this! Indeed, ought we to feel any surprise with the recompense she gives us when worked with chastised slaves, not the same that she used to bestow upon the labours of warriors? "

Why are we needlessly asking the old, old question of how long the soil will last for our people? This question has been settled by the experience of the older countries whose history we are considering. Why can we not realize as the Romans did that the solution of the problem is in our own hands, that it depends upon the man, his intelligence and his sympathetic control of the soil to maintain it in a productive state?

Pliny further says:

"The ancients were of the opinion, that before everything, moderation should be observed in the extent of a farm, for it was a favorite maxim of theirs that we ought to sow the less and plough the more; such too, I find, was the opinion entertained by Virgil, and indeed if we must confess the truth, it is the widespread domains that have been the ruin of Italy and soon will be that of the provinces as well. Six proprietors were in possession of one-half of Africa at the period when the Emperor Nero had them put to death. With that grandness of mind which was peculiarly his own and of which he ought not to lose the credit Cneius Pompeius would never purchase the lands that belonged to a neighbor. Mago has stated it as his opinion, that a person on buying a farm ought at once to sell his town house, an opinion, however, which savors of too great rigidity and is by no means conformable to the public good.

" The next point which requires our care is to employ a farm steward of experience, and upon this, too, Cato has given many useful precepts. Still, however, it must be sufficient for me to say that the steward ought to be a man nearly as clever as his master though without appearing to know it. It is a very worst plan, of all to have land tilled by slaves let loose from houses of correction, as, indeed, is the case with all work entrusted to men without hope."

Pliny then makes some pertinent remarks on the difference between farming for profit and farming for pleasure which has its application at the present time. "I may possibly appear guilty of some degree of rashness in making mention of a maxim of the ancients which will very probably be looked upon as quite incredible — 'that nothing is so disadvantageous as to cultivate the lands in the highest style of perfection.' E. Tarius Rufus, a man who, born in the very lowest ranks of life, by his military talents finally attained the consulship, and who in other respects adhered to the old-fashioned notions of thriftiness, made way with about 100,000,000 of sesterces, which, by the liberality of the late Emperor Augustus, he had contrived to amass, in buying up lands in Picenum and cultivating them in the highest style his object being to gain a name thereby; the consequence of which was, that his heir renounced the inheritance. Are we of the opinion, then, that ruin and starvation must be the necessary consequence of such a course as this? Yes, by Hercules! and the very best plan of all is to let moderation guide our judgment in all things. To cultivate land well is absolutely necessary, but to cultivate it in the very highest style is mere extravagance, unless, indeed, the work is done by the hands of the man's own family, his tenants, or those whom he is obliged to keep at any rate. But besides this, even when the owner tills the land himself, there are some crops which it is really not worth the while to gather if we only take into account the manual labor expended upon them. The olive, too, should never be too highly cultivated, nor must certain soils, it is said, be too carefully tilled, those of Sicily; hence it is that newcomers there so often find themselves deceived.

"In what way, then, can land be most profitably cultivated? Why, in the words of our agricultural oracles, 'by making good out of bad.' But here it is only right that we should say a word in justification of our forefathers who in their precepts on this subject had nothing else in view but the benefits of mankind: for when they use the term 'bad' here, they only mean to say that which costs the smallest amount of money. The principal object with them was in all cases to cut down expenses to the lowest possible sum; and it was in this spirit that they made the enactments which pronounced it criminal for a person who had enjoyed a triumph to be in possession among his other furniture of ten pounds weight of silver plate: which permitted a man upon the death of his farm steward, to abandon all his victories and return to the cultivation of his lands — such being the men the culture of whose farms the state used to take upon itself; and thus while they led our armies did the senate act as their steward."

In the interest of economy and efficiency we are urging sufficient diversification at least so that the farm may produce all that it can for the support of its own management. This is what Pliny says along this line: "It was in the same spirit, too, that those oracles of ours have given utterance to these other precepts to the effect that he is a bad agriculturist who has to buy what his farm might have supplied him with; that the man is a bad manager who does in the daytime what he might have done in the night except, indeed, when the state of the weather does not allow it; that he is the worse manager still who does on a work day what he might have done on a feast day, but that he is the very worst of all who works under cover in fine weather, instead of laboring in the field."

Pliny then cites a case which exemplifies his views as to the importance of man in promoting soil productivity. "I can not refrain from taking the present opportunity of quoting one illustration afforded us by ancient times, from which it will be found that it was the usage in those days to bring before the people even questions connected with the various methods employed in agriculture and it will be seen in what way men were accustomed to speak out in their own defense. C. Furius Chresimus, a freedman having found himself able, from a small piece of land, to raise far more abundant harvests than his neighbors could from the largest farms, became the object of very considerable jealousy among them, and was accordingly accused of enticing away the crops of others by the practice of sorcery. Upon this a day was named by Spurius Calvinus the *curule aedile,* for his appearance. Apprehensive of being condemned when the question came to be put to the vote among the tribes he had all his implements of husbandry brought into the forum together with his farm servants, well conditioned and well clad people, Piso says. The iron tools were of first rate quality, the mattocks were sturdy and strong, the plowshares ponderous and substantial, and the oxen sleek and in prime condition. When all this had been done, 'Here, Roman Citizens,' said he, 'are my implements of magic, but it is impossible for me to exhibit to your view or to bring into this forum those midnight toils of mine, those early watches, those sweats, and those fatigues.' Upon this, by the unanimous vote of the people he was immediately acquitted. Agriculture, in fact, depends upon the expenditure of labor and of exertion; and hence it is that the ancients were in the habit of saying, that it is the eye of the master that does more towards fertilizing a field than anything else."

Pliny then goes on to berate his own countrymen for their laxity and indifference in their pursuit of agriculture.

"Still, by Hercules! at the present day there are none to be found who have any acquaintance with much that has been handed down to us by the ancient writers; so much more comprehensive was the diligent research of our forefathers, or else so much more happily employed was their industry. It is a thousand years ago since Hesiod, at the very dawn, so to say, of literature, first gave precepts for the guidance of the agriculturist, an example which has since been followed by no small number of writers. Hence have originated considerable labours for ourselves, seeing that we have not only to enquire into the discoveries of modern times, but to ascertain as well what was known to the ancients, and this, too, in the very midst of that *oblivion which the heedlessness of the present day has so greatly* tended to generate. What causes then are we to assign for this lethargy, other than those feelings which we find actuating the public in general throughout all the world? New manners and usages, no doubt, have now come into vogue, and the minds of men are occupied with subjects of a totally different nature; the arts of avarice, in fact, are the only ones that are now cultivated.

"In days gone by, the sway and the destinies of states were bounded by their own narrow limits, and consequently the genius of the people was similarly circumscribed as well, through a sort of niggardliness that was thus displayed by Fortune: hence it became with them a matter of absolute necessity to employ the advantages of the understanding: kings innumerable received the homage of the arts, and in making a display of the extent of their resources, gave the highest rank to those arts, entertaining the opinion that it was through them that they should ensure immortality. Hence it was that due rewards, and the various works of civilization, were displayed in such vast abundance in those times. For these later ages, the enlarged boundaries of the habitable world, and the vast extent of our empire, have been a positive injury. Since the Censor has been chosen for the extent of his property, since the judge has been selected according to the magnitude of his fortune, since it has become the fashion to consider that nothing reflects a higher merit upon the magistrate and the general than a large estate, since the being destitute of heirs has begun to confer upon persons the very highest power and influence, since legacy-hunting has become the most lucrative of all professions, and since it has been considered that the only real pleasures are those of possessing, all the true enjoyments of life have been utterly lost sight of, and all those arts which have derived the name of liberal, from liberty, that greatest blessing of life, have come to deserve the contrary appellation, servility alone being the passport to profit.

"This servility each one has his own peculiar way of making most agreeable, and of putting in practice in reference to others, the motives and the hopes of all tending to the one great object, the acquisition of wealth: indeed, we may everywhere behold men even of naturally excellent qualities preferring to foster the vicious inclinations of others rather than cultivate their own talents. We may therefore conclude, by Hercules! that pleasure has now begun to live, and that life, truly so called, has ceased to be. As to ourselves, however, we shall continue our researches into matters now lost in oblivion, nor shall we be deterred from pursuing our task by the trivial nature of some of our details, a consideration which has in no way influenced us in our description of the animal world. And yet we find that Virgil, that most admirable poet, has allowed this to influence him, in his omission to enlarge upon the beauties of the garden; for, happy and graceful poet as he is, he has only culled what we may call the flower of his subject: indeed, we find that he has only named in all some fifteen varieties of the grape, three of the olive, the same number of the pear, and the citron of Assyria, and has passed over the rest in silence altogether."

Columella gives certain rules to be observed by agriculturists which are broadly as follows:

"That whoever studies agriculture must resolve to follow these ancient rules, prudence in management, the best way to lay out his money, and a certain resolution in what he does. For as Tremellius says that man is the likeliest to have a piece of ground truly cultivated, who has both skill, ability and will to look after it. For knowledge and the will are not alone sufficient, for such an undertaking without a purse, and again, a will to act and to lay out the money will avail nothing without art which is the chief thing to be considered in all business. In this lesson especially in agriculture the will and the purse without knowledge will frequently occasion great damage to the owner for work done without proper direction frequently disappoints him both in money and expectations. So that the diligent farmer who toils in improving the ground and in following the sure method of enriching himself will take care to consult the experienced husbandman."

He then says that on this the maxim of Mago the Carthaginian in the beginning of his book of husbandry is worthy of notice where he says, "let a farmer constantly reside in the country, to reap the full benefit of his farm; for he who loves a city life can have little prospect of advantage by his designs in agriculture."

That the ancients had a very profound feeling as to the importance of soil adaptation is gathered from this liberal translation from Virgil: "How necessary it is to consult the soil before we set about our work that by right knowledge of it we may only cultivate such plants upon it as are natural to it. That is we are to learn the temper and quality of our ground, the depth and substance of our soil and the color too, and then to consult carefully what plants are natural to such a soil and which plant will grow the most freely upon it. For if we do not take care to adapt our plants to our soil we must not hope for any tolerable success."

Liebig in his "Letters on Modern Agriculture," written about eighty years ago, says:

"The following statements, taken from the writings of Columella, Cato, Virgil, Varro, and Pliny, are calculated to enlighten agriculturists as to the actual point of 'progress' to which he has attained in the practice of his pursuit; and to show him that his modern teacher, after all, inculcates nothing that was not known to the world equally well, and often even much better, two thousand years ago. Reading the twelve books of Columella, after a perusal of our modern manuals of practical agriculture, is just like stepping from an arid and barren desert into a beautiful garden — so fresh and charming does everything appear." It seems singular that with these ancient precepts before him, which had been preserved through the Dark Ages, showing clearly the dynamic view of the soil held by the ancients, Liebig in his writings overlooked so much that was known and developed a narrow static view of the soil.

Liebig quotes from these ancient authors as follows:

"'The agriculturist requires one kind of knowledge, the herdsman another. The former ought to know what produce will answer best for his land; the latter must understand the most remunerative way of breeding cattle. Now, as the two pursuits are most intimately connected with each other, inasmuch as it is much more advantageous to use the provender grown on the field for home consumption, than to sell it; and as manuring mainly contributes to make a field fertile, and cattle are principally kept for the production of manure, therefore everybody who owns a farm must not only possess a knowledge of agriculture, but also of pasturage, and of the process of stall-feeding.' — (Columella).

"'Wherein does a good system of agriculture consist? In the first place, in thorough ploughing; in the second place, in thorough ploughing; and in the third place, in manuring.' — (Cato).

"'Superfluous moisture must be drawn off by ditches, either open or covered; in a chalky and stiff ground open ditches are preferable. Open ditches must be wider at the top than at the bottom; if they are of the same width throughout, the sides are undermined by water, and the falling earth fills up the ditch. Covered ditches are dug to the depth of three feet, half filled with small stones or coarse gravel, and the earth dug out is then thrown over the top and levelled. If neither gravel nor stones are to be got, then as many bundles of brushwood are thrown in as the narrow ditch will hold, and the whole is covered with earth. At the openings of the ditch, two stones are placed upright, as pillars, to support a third, like a small bridge; this keeps the ditch open.' — (Col.).

"'A soil to be fertile must, above all things, be light and friable, and this condition we seek to bring about by the operation of ploughing.' — (Virgil).

"'Ploughing the land simply means rendering the earth porous and friable, which most tends to increase its productiveness.'—(Cato).

"'The ancient Romans held, that a field which required harrowing could not have been well ploughed.'—(Columella).

"'A heavy soil should be turned up in autumn, and ploughed three times and the furrows be multiplied and drawn so closely together, that it may be barely possible to distinguish from which side the plough has proceeded; for by these means weeds are thoroughly rooted out. Fallow land must be ploughed until it is almost reduced to powder. The owner of a farm should often ascertain for himself whether it is properly ploughed. For this purpose he needs simply thrust a staff through the furrows (the Romans laid out their fields in broad undulating ridges, as may still be seen at the present day in the neighborhood of Nuremberg; only the Roman ridges were much broader); if the staff passes through unresisted it is a sure sign that the soil has been properly ploughed. Care must be taken to break clods of earth. Fields should be ploughed when neither too dry nor too wet; if the soil is too hard, the plough will not penetrate or it will simply tear off large clods. Even the best soil is unfruitful in its deeper layers, and the large lumps of earth torn up by the plough bring part of this subsoil to the top, which tends to deteriorate the arable surface soil. Always select for your fields those plants that may be best suited to their positions' (Cato); 'for all plants will not thrive equally well in all sorts of soils.'—(Varro). 'Some plants require a dry soil, others thrive best in moist ground.'—(Col.). 'Naturally moist ground answers best for pasturage.'—(Cato). 'Hay grown on naturally moist ground is better than where its production has to be stimulated by irrigation. A meadow plot in a plain must have a slight fall, that rain and other water may not gather on it in pools, but gently flow off.'—(Col.). The seeds intended for sowing should be picked out by hand, and pulse be previously soaked in saltpetre water.

"Still will the seeds, tho' chos'n with toilsome pains,
Degenerate, if man's industrious hand
Cull not each year the largest and the best.
'Tis thus, by destiny, all things decay
And retrograde, with motion unperceived.'
Virgil."

How difficult it is even at the present time to get our farmers to realize the importance of seed selection and plant breeding even though in Virgil's time the necessity for this was clearly *recognized.*

"'Take care to have your corn weeded twice with the hoe, and also by hand.' — (Cato).

"'Where want of space forbids this, green crops are grown alternately with cereals, and the loss of productive energy is restored by manuring.' — (Cato, Columella). 'Some agriculturists grow cereals on their fields two years in succession; proprietors, however, forbid this to their tenants.' — (Festus). 'The land must rest every second year, or be sown with lighter kinds of seeds, which prove less exhausting to the soil.' — (Varro).

"'Of the leguminous plants, lupines first deserve our attention, because they require the least labour, are cheapest, and of all seeds are the most profitable for the land; they give the best manure for impoverished fields, and will grow on a sterile soil.

"'Some of the leguminous plants manure the soil according to Saserna, and make it fruitful, whilst others exhaust it, and make it barren. Lupines, beans, peas, lentils, vetches are reported to manure the land. Of lupines and vetches I believe this to be truly the case, provided they be cut down green, and ploughed in before they are dry.' — (Columella)." Many of the present day have a feeling or belief that the use of legumes for improving the soil is a modern practice.

"'Linseed, poppy, and oats exhaust the soil.' — (Virgil). 'For fields that have suffered from the cultivation of these plants, manuring is the only efficacious means by which the lost productive energy of the earth is restored.' — (Columella). 'There are three kinds of manure: the best is the excrement of birds; then comes that of man; and lastly, that of cattle. The last also varies in quality. Asses' dung is the best; then follow sheep's dung, and that of goats, horses, and cattle; the least efficacious of all is the dung of swine. Where an estate consists altogether of corn-fields, there is no need to put on every kind of manure separately; but where there are plantations of trees, arable land, and pasturage, every kind of manure should be applied separately.' — (Columella). 'Pigeons' dung (guano) should be spread on meadows and gardens, or over the seeds.' — (Cato, Varro, Cassius). 'Horse-dung is about the best suited for meadow land, and so in general is that of beasts of burthen fed on barley; for manure produced from this cereal makes the grass grow luxuriantly.' — (Varro).

"'Agriculturists ought to know that a field will indeed lose its productive power when left altogether unmanured; but that, on the other hand, over-manuring is also very prejudicial. Let farmers, therefore, manure their fields often, rather than over much at a time.' — (Columella).

"'I have here one more remark to add, namely; that manure is best suited for the field when it is a year old. In summer it ought to be turned up and always kept moist, in order that the seeds of noxious weeds in it be rotted, and be not again returned to the land.' — (Col.).

"'The best fodder plants are lucerne, fenugreek (Foenum graecum), and vetches. Lucerne may be placed in the foremost rank of such plants; for when it is once sown, it lasts ten years, fattens lean cattle, and has a salutary action on sick cattle. It must be carefully weeded at first, lest the weeds choke the tender lucerne.' — (Columella).

"'A field is not sown entirely for the crop which is to be obtained the same year, but partly for the effect to be produced in the following; because there are many plants which, when cut down and left on the land, improve the soil. Thus, lupines, for instance, are ploughed into a poor soil, in lieu of manure.' —

(Varro). 'Mow your hay at the proper season, and take care not to be too late with it; you must cut it before the seed ripens, and store the best hay separately.' — (Cato). 'Mossy meadows may be improved by a fresh sowing, or by manuring; but neither of these operations will answer so well as frequent strewing with ash, which destroys the moss.' — (Columella)."

Pliny has much to say on the different kinds of soil and their adaptations, on the different kinds of manures and on the influence of one crop upon another. This gives us an insight into the Romans' knowledge of the soil, their appreciation of the natural differences in soil types and of how they tried to avail themselves of the differences in attempting to build up a strong system of agriculture which would endure but which Pliny saw could not prevail against the changes in the social and political life of the people which had long before set in, the influences even then giving signs of incapacity which threatened the existence of the empire itself. It is well worth reading the following extracts from his work to gain a knowledge of the agriculture of his time as he saw it.

"Next after the influences of the heavens, we have to treat of the earth, a task that is in no way more easy than the previous one. It is but rarely that the same soil is found suited to trees as well as corn; indeed, the black earth which prevails in Campania is not everywhere found suited to the vine, nor yet that which emits light exhalations, or the red soil that has been so highly praised by so many. The cretaceous earth that is found in the territory of Alba Pompeia, and an argillaceous soil, are preferred to all others for the vine, although, too, they are remarkably rich, a quality that is generally looked upon as not suited to that plant. On the other hand, again, the white sand of the district of Ticinum, the black sand of many other places, and the red sand as well, even though mixed with a rich earth, will prove unproductive.

"The very signs, also, from which we form our judgment are often very deceptive; a soil that is adorned with tall and graceful trees is not always a favourable one, except, of course, for those trees. What tree, in fact, is there that is taller than the fir? and yet what other plant could possibly exist in the same spot? Nor ought we always to look upon verdant pastures as so many proofs of richness of soil; for what is there that enjoys a greater renown than the pastures of Germany? and yet they consist of nothing but a very thin layer of turf, with sand immediately beneath. Nor yet is the soil which produces herbage of large growth always to be looked upon as humid; no, by Hercules! no more than a soil is to be looked upon as unctuous and rich, which adheres to the fingers — a thing that is proved in the case of the argillaceous earths. The earth when thrown back into the holes from which it has just been dug will never fill it, so that it is quite impossible by that method to form any opinion as to its density or thinness. It is the fact, too, that every soil, without exception, will cover iron with rust. Nor yet can we determine the heaviness or lightness of soils in relation to any fixed and ascertained weight: for what are we to understand as the standard weight of earth? A soil, too, that is formed from the alluvion of rivers is not always to be recommended, for there are some crops that decay all the sooner in a watery soil; indeed, those soils even of this description which are highly esteemed, are never found to be long good for any kind of vegetation but the willow.

"Among other proofs of the goodness of soil, is the comparative thickness of the stem in corn. In Laborium, a famous champaign country of Campania, the stalk is of such remarkable thickness that it may be used even to supply the place of wood: and yet this very soil, from the difficulty that is everywhere experienced in cultivating it, and the labour required in working it, may be almost said to give the husbandman more trouble by its good qualities than it could possibly have done by reason of any defects. The soil, too, that is generally known as charcoal earth, appears susceptible of being improved by being planted with a poor meagre vine: and tufa, which is naturally rough and friable, we find recommended by some authors. Virgil, too, does not condemn for the vine a soil which produces fern: while a salted earth is thought to be much better entrusted with the growth of vegetation than any other, from the fact of its being comparatively safe from noxious insects breeding there. Declivities, too, are far from unproductive, if a person only knows how to dig them properly; and it is not all champaign spots that are less accessible to the sun and wind than is necessary for their benefit."

The ancients recognized the influence of drainage, of the removal of stones from the surface and of the occurrence of hard-pan as affecting the local conditions of climate on the soil, for Pliny says: "In every subject there are certain deep and recondite secrets, which it is left to the intelligence of each to penetrate. Do we not, for instance, find it the fact, that soils which have long offered opportunities for a sound judgment being formed on their qualities have become totally altered? In the vicinity of Larissa, in Thessaly, a lake was drained; and the consequence was, that the district became much colder, and the olive-trees which had formerly borne fruit now ceased to bear. When a channel was cut for the Hebrus, near the town of Ænos, the place was sensible of its nearer approach, in finding its vines frost-bitten, a thing that had never happened before; in the vicinity, too, of Philippi, the country having been drained for cultivation, the nature of the climate became entirely altered. In the territory of Syracuse, a husbandman, who was a stranger to the place, cleared the soil of all the stones, and the consequence was, that he lost his crops from the accumulation of mud; so that at last he was obliged to carry the stones back again. In Syria again, the ploughshare which they use is narrow, and the furrows are but very superficial, there being a rock beneath the soil that in summer scorches up the seeds.

"Then, too, the effects of excessive cold and heat in various places are similar; thus, for instance, Thrace is fruitful in corn, by reason of the cold, while Africa and Egypt are so in consequence of the heat that prevails there. At Chalcia, an island belonging to the Rhodians, there is a certain place which is so remarkably fertile, that after reaping the barley that has been sown at the ordinary time, and gathering it in; they immediately sow a fresh crop, and reap it at the same time as the other corn. A gravelly soil is found best suited for the olive in the district of Venafrum, while one of extreme richness is required for it in Baetica. The vines of Pucinum are ripened upon a rock, and the vines of Caecubum are moistened by the waters of the Pomptine marshes; so great are the differences that have been detected by human experience in the various soils. Caesar Vopiscus, when pleading a cause before the Censors, said that the fields of Rosia are the very marrow of Italy, and that a stake, left in the ground there one day, would be found covered by the grass the next: the soil, however, is only esteemed there for the purposes of pasturage. Still, however, Nature has willed that we should not remain uninstructed, and has made full admission as to existing defects in soil, even in cases where she has failed to give us equal information as to its good qualities: we shall begin, therefore, by speaking of the defects that are found in various soils."

Pliny then attempts to show some of the defects of soils, pointing out certain symptoms that can be recognized — "If it is the wish of a person to test whether a soil is bitter, or whether it is thin and meagre, the fact may be easily ascertained from the presence of black and undergrown herbs. If, again, the herbage shoots up dry and stunted, it shows that the soil is cold, and if sad and languid, that it is moist and slimy. The eye, too, is able to judge whether it is a red earth or whether it is argillaceous, both of them extremely difficult to work, and apt to load the harrow or ploughshare with enormous clods; though at the same time it should be borne in mind that the soil which entails the greatest amount of labour is not always productive of the smallest amount of profit. So too, on the other hand, the eye can distinguish a soil that is mixed with ashes or with white sand, while earth that is sterile and dense may be easily detected by its peculiar hardness, at even a single stroke of the mattock."

Pliny gives a very interesting account which is taken in part from his campaigns in England of the use of marl and limestone on the soils in improving soil conditions.

"There is another method, which has been invented both in Gaul and Britain, of enriching earth by the agency of itself, being . . . and that kind known as marl. This soil is looked upon as containing a greater amount of fecundating principles, and acts as a fat in relation to the earth, just as we find glands existing in the body; which are formed by a condensation of the fatty particles into so many kernels.

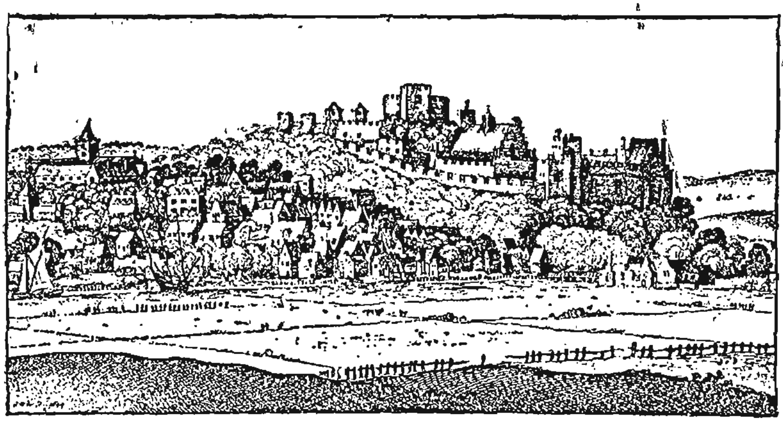


FIG. 29. An English castle with village and cultivated fields. From an engraving supposed to have been made in 1644. (Then as now level alluvial lands, as shown in the foreground, were highly valued for pasture and were used in common while the arable fields were some distance from the village and generally arranged in narrow strips separated only by open grass balks, no enclosures being allowed.)

"This mode of proceeding, too, has not been overlooked by the Greeks; indeed, what subject is there that they have not touched upon? They call by the name of leucargillon a white argillaceous earth which is used in the territory of Megara, but only where the soil is of a moist, cold nature.

"It is only right that I should employ some degree of care and exactness in treating of this marl, which tends so greatly to enrich the soil of the Gallic provinces and the British islands.

There were formerly but two varieties known, but more recently, with the progress of agricultural knowledge, several others have begun to be employed; there being, in fact, the white, the red, the columbine, the argillaceous, the tufaceous, and the sandy marls. It has also one of these two peculiarities, it is either rough or greasy to the touch; the proper mode of testing it being by the hand. Its uses, too, are of a twofold nature — it is employed for the production of the cereals only, or else for the enrichment of pasture land as well. The tufaceous kind is nutrimental to grain, and so is the white; if found in the vicinity of springs, it is fertile to an immeasurable extent; but if it is rough to the touch, when laid upon the land in too large a quantity, it is apt to burn up the soil. The next kind is the red marl, known as acaunumarga, consisting of stones mingled with a thin sandy earth. These stones are broken upon the land itself, and it is with considerable difficulty during the earlier years that the stalk of the corn is cut, in consequence of the presence of these stones; however, as it is remarkably light, it only costs a carriage one-half of the outlay required in using the other varieties. It is laid but very thinly on the surface, and it is generally thought that it is mixed with salt. Most of these varieties, when once laid on the land, will fertilize it for fifty years, whether for grain or for hay.

"Of the marls that are found to be of an unctuous nature, the best is the white. There are several varieties of it: the most pungent and biting being the one already mentioned. Another kind is the white chalk that is used for cleaning silver; it is taken from a considerable depth in the ground, the pits being sunk, in most instances, as much as one hundred feet. These pits are narrow at the mouth, but the shafts enlarge very considerably in the interior, as in the case in mines; it is in Britain more particularly that this chalk is employed. The good effects of it are found to last full eighty years; and there is no instance known of an agriculturist laying it twice on the same land during his life. A third variety of white marl is known as glisomarga; it consists of fullers' chalk mixed with an unctuous earth, and is better for promoting the growth of hay than grain; so much so, in fact, that between harvest and the ensuing seedtime, there is cut a most abundant crop of grass. While the corn is growing, however, it will allow no other plant to grow there. Its effects will last so long as thirty years; but if laid too thickly on the ground, it is apt to choke up the soil, just as if it had been covered with signine cement. The Gauls give to the columbine marl in their language the name of eglecopala; it is taken up in solid blocks like stone, after which it is so loosened by the action of the sun and frost, as to split into laminae of extreme thinness; this kind is equally beneficial for grass and grain. The sandy marl is employed if there is no other at hand, and on moist slimy soils, even when other kinds can be procured.

"The Ubii are the only people that we know of, who, having an extremely fertile soil to cultivate, employ methods of enriching it; wherever the land may happen to be, they dig to a depth of three feet, and, taking up the earth, cover the soil with it in other places a foot in thickness; this method, however, to be beneficial, requires to be renewed at the end of every ten years. The Ædui and the Pictones have rendered their lands remarkably fertile by the aid of limestone, which is also found to be particularly beneficial to the olive and the vine. Every marl, however, requires to be laid on the land immediately after ploughing, in order that the soil may at once imbibe its properties; while at the same time, it requires a little manure as well, as it is apt, at first, to be of too acrid a nature, at least where it is not pasture land that it is laid upon; in addition to which, by its very freshness it may possibly injure the soil, whatever the nature of it may be; so much so, indeed, that the land is never fertile the first year after it has been employed. It is a matter of consideration also for what kind of soil the marl is required; if the soil is moist, a dry marl is best suited for it; and if dry, a rich unctuous marl. If, on the other hand, the land is of a medium quality, chalk or columbine marl is the best suited for it."

The use of ashes and manures of various kinds was strongly recommended by the ancients and Pliny's description of their practices which follows is very interesting.

"The agriculturists of the parts of Italy beyond the river Padus, are such admirers of ashes for this purpose, that they even prefer it as a manure to the dung of beasts of burden; indeed, they are in the habit of burning dung for this purpose, on account of its superior lightness. They do not, however, use them indiscriminately upon the same soil, nor do they employ ashes for promoting the growth of shrubs, nor, in fact, of some of the cereals, as we shall have occasion to mention hereafter. There are some persons who are of opinion also that dust imparts nutriment to grapes, and cover them with it while they are growing, taking care to throw it also upon the roots of the vines and other trees. It is well known that this is done in the province of Gallia Narbonensis, and it is a fact even better ascertained that the grapes ripen all the sooner for it; indeed, the dust there contributes more to its ripeness than the heat of the sun.

"There are various kinds of manure, the use of which is of very ancient date. In the times of Homer even, the aged king is represented as thus enriching the land by the labour of his own hands. Tradition reports that King Augeas was the first in Greece to make use of it, and that Hercules introduced the practice into Italy; which country has, however, immortalized the name of its king, Stercutus, the son of Faunus, as claiming the honour of this invention. M. Varro assigns the first rank for excellence to the dung of thrushes kept in aviaries, and lauds it as being not only food for land, but excellent food for oxen and swine as well; indeed, he goes so far as to assert that there is no food that they will grow fat upon more speedily. We really have some reason to augur well of the manners of the present day, if it is true that in the days of our ancestors there were aviaries of such vast extent as to be able to furnish manure for the fields.

"Columella gives the second rank to pigeon manure, and the next to that of the poultry-yard; but he condemns that of the aquatic birds. Some authors, again, are agreed in regarding the residue of the human food as the very best of all manures; while others would only employ the superfluous portion of our drink, mixing with it the hair that is to be found in the curriers' workshops. Some, however, are for employing this liquid by itself, though they would mix water with it once more, and in larger quantities even than when originally mixed with the wine at our repasts; there being a double share of noxious qualities to correct, not only those originally belonging to the wine, but those imparted to it by the human body as well. Such are the various methods by which we vie with each other in imparting nutriment to the earth even.

"Next to the manures above mentioned, the dung of swine is highly esteemed, Columella being the only writer that condemns it. Some, again, speak highly of the dung of all quadrupeds, that have been fed on cytisus, while there are others who prefer that of pigeons. Next to these is the dung of goats, and then of sheep; after which comes that of oxen, and last of all, of the beasts of burden. Such were the distinctions that were established between the various manures among the ancients, such the precepts that they have left us, and these I have here set forth as being not the mere subtle inventions of genius, but because their utility has been proved in the course of a long series of years. In some of the provinces, too, which abound more particularly in cattle, by reason of their prolific soil, we have seen the manure passed through a sieve like so much flour, and perfectly devoid, through lapse of time, of all bad smell or repulsive look, being changed in its appearance to something rather agreeable than otherwise. In more recent times it has been found that the olive thrives more particularly in soil that has been manured with the ashes of the lime-kiln. To the ancient rules Varro has added, that corn land should be manured with horse-dung, that being the lightest manure of all, while meadow land, he says, thrives better with a manure of a more heavy nature, and supplied by beasts that have been fed upon barley; this last tending more particularly to the better growth of grass. Some persons, indeed, prefer the dung of the beasts of burden to that of oxen even, the manure of the sheep to that of the goat, and the manure of the ass to all others, the reason being that that animal masticates the most slowly of them all. Experience, however, has pronounced against these dicta of Varro and Columella; but it is universally agreed by all writers that there is nothing more beneficial than to turn up a crop of lupines, before they have podded, with either the plough or the fork, or else to cut them and bury them in heaps at the roots of trees and vines. It is thought, also, that in places where no cattle are kept, it is advantageous to manure the earth with stubble or even fern. 'You can make manure,' Cato says, 'of litter, or else of lupines, straw, beanstalks, or the leaves of the holm-oak and quercus. Pull up the wallwort from among the crops of corn, as also the hemlock that grows there, together with the thick grass and sedge that you find growing about the willow-plots; of all this, mixed with rotten leaves, you may make a litter for sheep and oxen. If a vine should happen to be but poor and meagre, prune the shoots of it, and plough them in round about it.' The same author says, also, 'when you are going to sow corn in a field, fold your sheep there first.'

"Cato says, also, that there are some crops which tend to nourish the earth: thus, for instance, corn land is manured by the lupine, the bean, and the vetch; while on the other hand, the chick-pea exercises a contrary influence, both because it is pulled up by the roots and is of a salt nature; the same is the case, too, with barley, fenugreek, and fitches, all of which have a tendency to burn up corn land, as, in fact, do all those plants which are pulled up by the roots. Take care, too, not to plant stone-fruits on corn land. Virgil is of opinion, also, that corn land is scorched by flax, oats, and poppies. . . ."

"The proper method of manuring is here a very important subject for consideration — we have already treated of it at some length in the preceding Book. The only point that is universally agreed upon is, that we must never sow without first manuring the ground; although in this respect even there are certain rules to be observed. Millet, panic, rape, and turnips should never be sown in any but a manured soil. If, on the other hand, the land is not manured, sow wheat there in preference to barley. The same, too, with fallow lands; though in these it is generally recommended that beans should be sown. It should be remembered, however, that wherever beans are sown, the land should have been manured at as recent a period as possible. If it is intended to crop ground in autumn, care must be taken to plough in manure in the month of September, just after rain has fallen. In the same way, too, if it is intended to sow in spring, the manure should be spread in the winter. It is the rule to give eighteen cart-loads of manure to each jugerum, and to spread it well before ploughing it in, or sowing the seed. If this manuring, however, is omitted, it will be requisite to spread the land with aviary dust just before hoeing is commenced. To clear up any doubts with reference to this point, I would here observe that the fair price for a cart-load of manure is one denarius; where, too, sheep furnish one cart-load, the larger cattle should furnish ten: unless this result is obtained, it is a clear proof that the husbandman has littered his cattle badly."

Pliny gives the following very interesting observations on cultivation and farm management.

"Among the Romans the cultivation of the vine was introduced at a comparatively recent period, and at first, as indeed they were obliged to do, they paid their sole attention to the culture of the fields. The various methods of cultivating the land will now be our subject; and they shall be treated of by us in no ordinary or superficial manner, but in the same spirit in which we have hitherto written; enquiry shall be made with every care first into the usages of ancient days, and then into the discoveries of more recent times, our attention being devoted alike to the primary causes of these operations, and the reasons upon which they are respectively based . . . and the more so, from the fact that those writers who have hitherto treated of them with any degree of exactness, seem to have written their works for the use of any class of man but the agriculturist.

" First of all, then, I shall proceed in a great measure according to the dicta of the oracles of agriculture; for there is no branch of practical life in which we find them more numerous or more unerring. And why should we not view in the light of oracles those precepts which have been tested by the infallibility of time and the truthfulness of experience?

" To make a beginning, then, with Cato — ' The agricutural population,' says he, ' produces the bravest men, the most valiant soldiers, and a class of citizens the least given of all to evil designs. — Do not be too eager in buying a farm. — In rural operations never be sparing of your trouble, and, above all, when you are purchasing land. — A bad bargain is always a ground for repentance. — Those who are about to purchase land, should always have an eye more particularly to the water there, the roads, and the neighborhood.' Each of these points is susceptible of a very extended explanation, and replete with undoubted truths. Cato recommends, too, that an eye should be given to the people in the neighborhood, to see how they look: ' For where the land is good,' says he, 'the people will look well-conditioned and healthy.'

" Atilius Regulus, the same who was twice consul in the Punic War, used to say that a person should neither buy an unhealthy piece of land in the most fertile locality, nor yet the very healthiest spot if in a barren country. The salubrity of land, however, is not always to be judged of from the looks of the inhabitants, for those who are well-seasoned are able to withstand the effects of living in pestilent localities even. And then, besides, there are some localities that are healthy during certain periods of the year only; though, in reality, there is no soil that can be looked upon as really valuable that is not healthy all the year through. ' That is sure to be bad land against which its owner has a continual struggle.' Cato recommends us before everything, to see that the land which we are about to purchase not only excels in the advantages of locality, as already stated, but is really good itself. We should see, too, he says, that there is an abundance of manual labour in the neighborhood, as well as a thriving town; that there are either rivers or roads, to facilitate the carriage of the produce; that the buildings upon the land are substantially erected, and that the land itself bears every mark of having been carefully tilled — a point upon which I find that many persons are greatly mistaken, as they are apt to imagine that the negligence of the previous owner is greatly to the purchaser's advantage; while the fact is, that there is nothing more expensive than the cultivation of a neglected soil.

"For this reason it is that Cato says that it is best to buy land of a careful proprietor, and that the methods adopted by others ought not to be hastily rejected — that it is the same with land as with mankind — however great the proceeds, if at the same time it is lavish and extravagant, there will be no great profits left. Cato looks upon a vineyard as the most profitable investment; and he is far from wrong in that opinion, seeing that he takes such particular care to retrench all superfluous expenses. In the second rank he places gardens that have a good supply of water, and with good reason, too, supposing always that they are near a town. The ancients gave to meadow land the name of 'parata,' or lands 'always ready.'

"Cato being asked, on one occasion, what was the most certain source of profit, 'Good pasture land,' was his answer: upon which, enquiry was made what was the next best. 'Pretty good pasture lands,' said he — the amount of all of which is, that he looked upon that as the most certain source of income which stands in need of the smallest outlay. This, however, will naturally vary in degree, according to the nature of the respective localities; and the same is the case with the maxim to which he gives utterance, that a good agriculturist must be fond of selling. The same, too, with his remark, that in his youth a landowner should begin to plant without delay, but that he ought not to build until the land is fully brought into cultivation, and then only a little at a time; and that the best plan is, as the common proverb has it, 'To profit by the folly of others;' taking due care, however, that the keeping up of a farm-house does not entail too much expense. Still, however, those persons are guilty of no falsehood who are in the habit of saying that a proprietor who is well housed comes all the oftener to his fields, and that 'the master's forehead is of more use than his back.'"

The effect of plant associations and the distance apart that plants should be set was quite fully understood by the ancients as is shown from the following statement made by Pliny.

"The shadows of trees are possessed of certain properties. That of the walnut is baneful and injurious to man, in whom it is productive of head-ache, and it is equally noxious to everything that grows in its vicinity. The shadow, too, of the pine has the effect of killing the grass beneath it; but in both of these trees the foliage presents an effectual resistance to the winds, while, at the same time, the vine is destitute of such protection. The drops of water that fall from the pine, the quercus, and the holm-oak are extremely heavy, but from the cypress none fall; the shadow, too, thrown by this last tree is extremely small, its foliage being densely packed. The shadow of the fig, although widely spread, is but light, for which reason it is allowed to be planted among vines. The shadow of the elm is refreshing and even nutrimental to whatever it may happen to cover; though, in the opinion of Atticus, this tree is one of the most injurious of them all; and, indeed, I have no doubt that such may be the case when the branches are allowed to become too long; but at the same time I am of opinion that when they are kept short it can be productive of no possible harm. The plane also gives a very pleasant shade, though somewhat dense: but in this case we must look more to the luxuriant softness of the grass beneath it than the warmth of the sun; for there is no tree that forms a more verdant couch on which to recline.

"The poplar gives no shade whatever, in consequence of the incessant quivering of its leaves: while that of the alder is very dense, but remarkably nutritive to plants. The vine affords sufficient shade for its wants, the leaf being always in motion, and from its repeated movements tempering the heat of the sun with the shadow that it affords; at the same time too it serves as an effectual protection against heavy rains. In nearly all trees the shade is thin, where the footstalks of the leaves are long.

"This branch of knowledge is one by no means to be despised or deserving to be placed in the lowest rank, for in the case of every variety of plant the shade is found to act either as a kind nurse or a harsh step-mother. There is no doubt that the shadow of the walnut, the pine, the pitch-tree, and the fir is poisonous to everything it may chance to light upon.

"A very few words will suffice for the water that drops from the leaves of trees. In all those which are protected by a foliage so dense that the rain will not pass through the drops are of a noxious nature. In our enquiries, therefore, into this subject it will be of the greatest consequence what will be the nature developed by each tree in the soil in which we are intending to plant it. Declivities, taken by themselves, require smaller intervals between the trees, and in localities that are exposed to the wind it is beneficial to plant them closer together. However, it is the olive that requires the largest intervals to be left, and on this point it is the opinion of Cato, with reference to Italy, that the very smallest interval ought to be twenty-five feet, and the largest thirty: this, however, varies according to the nature of the site. The olive is the largest of all the trees in Baetica: and in Africa — if, indeed, we may believe the authors who say so — there are many olive-trees that are known by the name of milliariae, being so called from the weight of oil that they produce each year. Hence it is that Mago has prescribed an interval between these trees of no less than seventy-five feet every way, or of forty-five at the very lowest, when the soil happens to be meagre, hard, and exposed to the winds. There is no doubt, however, that Baetica reaps the most prolific harvests from between her olives.

"It will be generally agreed that it is a most disgraceful piece of ignorance to lop away the branches more than is absolutely necessary in trees of vigorous growth, and so precipitate old age; as also, on the other hand, what is generally tantamount to an avowal of unskilfulness on the part of those who have planted them, to have to cut them down altogether. Nothing can reflect greater disgrace upon agriculturists than to have to undo what they have done, and it is therefore much the best to commit an error in leaving a superfluity of room."

The history of Greece and of Rome and their agriculture as described by themselves has been sketched perhaps more fully than is necessary in a work of this kind but it all seems to have a bearing upon the character of the people and to have a meaning in the study of their agriculture. The eastern countries, such as Asia Minor and Mesopotamia, had great wealth, — the western countries, Greece and Rome, were intellectually strong and the people were vigorous, venturesome and independent in their thoughts and actions.

So far as history permits one to judge it is apparent that Rome was not situated in a fertile country and that Greece was not noted for the abundance of her yields. The whole purpose of the Roman and Greek life was to acquire wealth and foodstuffs in the countries of others. Rome was a great trading city and through historic times endeavored to keep the sea routes open to Egypt for her supply of grain.

The early history of Roumania marks a constant and continual warfare between the Romans and the Turks for her supply of grain. Rome from the earliest period of her history has been dependent principally upon Egypt and Roumania for her supply of grain.

Carthage was purely a trading city, which grew in power from her vast trade from one end of the Mediterranean to the other. Rome was not only jealous of Carthage but felt that her whole existence after she had organized the Italian states depended upon her supremacy of the sea routes for providing grain as well as other materials of commerce. Rome deliberately captured a Carthaginian vessel and set workmen to copy it and to build up a great fleet through which she finally destroyed Carthage and the Carthaginian trade.

So far as history reveals Carthage was not situated in a productive agricultural area. The average wheat yield of Tunis in 1909 to 1913 was 5.08 bushels per acre. There are no records or remains of vast irrigation works around Carthage nor did Carthage seem to show a development of this kind. It was purely a trading port with vast warehouses for the buying and selling of grain and of fruit and of articles of commerce from and to the countries of the Mediterranean. History does not suggest any great agricultural development and it is doubtful if the yields of grain at that early period were any larger than the yields obtained at this time. When Carthage was destroyed, when the city was completely burned to the ground by the Romans, when the remnant of its people were sold into slavery and Rome assumed the mastery of the seas Carthage was finished — there was nothing left. There was no opportunity and no desire or purpose in attempting to maintain its agriculture.

In Greece a large proportion of the country is rough and mountainous and has never afforded more than a scanty pasturage or rough mountain crops. Athens itself is in the midst of a desert with no signs of great irrigation works as are found in Mesopotamia. They had their wheat fields on the plains of Thessaly and a few other favored spots, but much of their grain supply must have come from Egypt. The Greeks were inclined to move around and to settle in other countries and they settled as individuals in Italy and Spain to the West, in Asia Minor, Mesopotamia, Persia, Syria and Egypt and along the north shore of Africa. They were not bent upon conquest but mixed in with the people for trading purposes, storekeeping, and for as peaceful and quiet a life as the times would permit.

The Romans on the other hand were conquerors. They deliberately set out to conquer the world. On the whole their conquests were beneficent. They exercised sovereignty but did not attempt to displace the ruling powers or the occupation of the people, and contented themselves with the revenues and the supplies which they could draw to their own use.

There is no indication in history that the soils of Rome or of Italy were ever very productive. It is doubtful if the yield of wheat on the average ever exceeded present yields of 15.6 bushels per acre and perhaps did not exceed the present yields of the Roman Campagna which is between 10 and 11 bushels per acre and is about equal to the present yield of wheat in our own Southern States. That there were many individuals who exceeded such averages is certain for Pliny lays great stress upon the yields obtained by their great generals and by men who understood the art of cultivation. If they had in those early days bounteous yields why should they have fought for centuries with the Turks over the grain fields of Roumania?

Roumania is a country tucked away in a quiet corner far away from any of the Mediterranean ports, very mountainous but with broad valleys, considerably farther north than Rome. Primitive methods have always prevailed and yet after these centuries of occupation without the use of fertilizers this country is to-day producing an average yield of wheat of 16.7 bushels per acre (1909–1913), greater than the average production of wheat in the United States, and having a surplus in normal years of 40,000,000 bushels of corn, 50,000,000 bushels of wheat and 11,000,000 bushels of barley to throw into the world's markets.

The Romans drew heavily on the supplies of grain in Egypt where under irrigation the present yields (1909–1913) are given as 25.4 bushels per acre.

Chapter VII

THE RENAISSANCE OF AGRICULTURE

After an interlude of 1500 years of the Dark Ages, the curtain rises on the great drama and the scene shifts to the north of Europe, to England, Germany and France. Very weak are the beginnings of agriculture and of agricultural thought and reasoning. All has been forgotten by the masses of men and even with the philosophers it is like one trying to arouse from a prolonged slumber. Childish suggestions begin to appear, they wonder what makes the plant grow, what it is composed of, what part the soil takes. The only thing that can be said about this period is that the day is dawning and recollection begins in a feeble way to assert its power on the brain.

Palissy in 1563, Van Helmont (1577 to 1644), Glauber in 1650, Boyle in 1678 and later Külbel and Boerhaave have their curiosity aroused as to what plants consist of and what takes place in their growth in the soil. The ancients had their four elements, fire, earth, air and water, into which they attempted to divide all material things and to explain all natural phenomena. Van Helmont argued from his own experiments that the plant was composed of water and was derived from water. Boyle accepted this explanation but as he found on distilling plants that he obtained both oil and salts, he explained that these also were derived from water. Palissy argued that the ash of plants was derived from the soil and that when we added ashes as fertilizers we were adding something that plants had already extracted from the soil and which they would again take up. Glauber having obtained saltpeter from cattle sheds held that this was the principal source of vegetation and explained that the effectiveness of manures was due entirely to the formation of this substance. Külbel on the other hand held that humus was the principle of vegetation. Boerhaave appears to have been the first of the philosophers of that time to suggest that the plants absorbed the juices of the earth, a view that the ancients had taken as shown by the writings of Pliny. This was the thought that prevailed up to 1800, when the phlogistic theory which had come down from the teachings of the philosopher Aristotle was finally exploded with the beginnings of modern scientific research.

The condition of agriculture about 300 years ago at the end of the baronial period can best be understood by a picture of the times. Imagine a huge castle with minarets, turrets, donjons, walls, portcullis, moats, drawbridge, and such other details as are necessary for the protection of the knight, his family, friends and retainers and from which they would foray for meat or for war. We are not interested in the castle and, therefore, will not take the time to describe its form or its people. We are interested in the people in the village, in the farmers who are cultivating the land around the castle. There are thirty or forty of these families, who raise crops on fields of small dimensions with certain pasture lands in common, occupying their lands at the will of the knight or baron and obligated to him for work on his lands and for his defense. Every one is constantly on the watch for danger, the men to join the fighting forces, the women and children to drive their cattle into the castle, if there is room, or into the mountains to protect them from plunder. When the enemy was overcome, driven off, or a truce arranged, these poor people came back to their homes, if indeed they were left standing, and again occupied their gardens.

Such was the life the farmers of England maintained when the country had a population of about three million, with a considerable portion even then in the cities or in unproductive labor in the castles. Such intermittent care was bestowed upon their gardens that the soils often became foul with weeds to a point where new land was taken up on the other side of the castle in order to obtain yields that were at all commensurate with their necessities. At this period in English agriculture the best authorities indicate that the average yield of wheat was less than 12 bushels per acre.

The same conditions prevailed in Germany and the baronial farm records indicate a yield of about 12 bushels per acre of wheat in Germany at that period. The same conditions prevailed in France. There was utter neglect on the part of the farmers through force of necessity and the conditions of living at that time. There was a condition of internecine warfare far worse for agriculture than were the campaigns of the Persians or of the Romans. Land tenures were uncertain, taxes were heavy, individual initiative was hopelessly oppressed and the people had forgotten the laws, methods and precepts worked out by the ancients.

Then in 1701 Jethro Tull came onto the stage and taught, in a voice that was heard all over northern Europe, that plants took up fine particles of soil and, therefore to produce good crops it was necessary to plow and cultivate the soil most thoroughly. This was the first and most important principle of agriculture as taught by Cato, Columella and Pliny, not for the reasons given by Tull which were wrong, but in spite of the faulty logic this gave the one impetus that was needed to the agriculture of that time and which marked the beginning of the renaissance of agriculture in Europe. This brought the agriculturists of Europe to their senses and started them on a campaign of better farming. Gradually they began to domesticate and breed up their wild cattle, gradually they brought system into the cultivation of their soils and into their cropping, gradually they began to use legumes, to rotate their crops, to select their seeds, to care for their manure and to fertilize their lands, in other words to build up their agriculture on substantially the lines worked out by the Romans, Greeks, and Chinese long before the veil of darkness had descended upon the earth and had wiped out the experience and knowledge of the ancients.

To-day the average yield of wheat in England is counted at 32.4 bushels per acre, in Germany 31.7 bushels per acre, and in

France 19.1 bushels per acre, and the yields so far as we can see are continuing to rise. This has been brought about by man in a more intelligent use of his labor and of his mentality, in the more intelligent and more rational treatment of the soil. The period of the agricultural renaissance has been completed and accomplished so far as Europe is concerned, their soils have been brought under intelligent control, the methods have become well organized, and their yields are larger and more uniform.

The Japanese say that their oldest soils are the most valued because they have been better regulated and are under better control. It has required about 300 years in the north of Europe to increase the wheat yields from about 12 bushels to 30 bushels. The United States appears to be about 100 years behind Europe in the matter of yield of wheat per acre. In the past 41 years the average yield of wheat in the United States has increased from about 11.5 bushels per acre to somewhere in the neighborhood of 16 bushels per acre. We say in the neighborhood of 16 bushels for from the text figures it appears safe to assume that it would have reached this figure in 1922 had it not been for the period of the War when much new land and unsuitable land was put into wheat from the stimulus of high prices and because of rust and the long period of drought which has prevailed in parts of our western prairie states. This gives an increase of 4½ bushels or 1.12 bushels in ten years. If this normal rate of increase continues it would require about 100 years for the average yields in the United States to approach the present average yields in Europe.

A dispassionate reading of the history of the world indicates that on the whole the practice of the present day in the cultivation of the soil has not advanced greatly over the practice of the ancients. The knowledge that has been acquired in the last century of material things is far greater than was available to the ancients. What we will do with the knowledge so acquired, when it becomes thoroughly organized and applied, the future only can tell. It is important for us now to pause and consider what this knowledge is, how it has come to us, how it has affected our social and industrial conditions, to get some conception of how much better prepared we are through knowledge than the ancients were to solve the problems of the future.

Down to the period of 1800 it has been shown that we had little more idea as to the constitution of material things than the ancients. Throughout the whole range of human existence the world activities were on a basis of the manpower and the animal power. Certain principles connected with the laws of nature were known even to the ancients but the application of these principles had hardly been made before the beginning of the 19th century. Suddenly and without warning a group of men came forward who through invention and scientific thought have changed the whole order of things, and this in a very short period compared with the times that have gone before. So numerous and so vast have been the discoveries that it is impossible in a single volume to follow them logically or in sequence, but it is very necessary for us to pause and make a superficial survey in order to understand something of the responsibilities and of the possibilities of extending our knowledge of the soils and of agriculture in the future. So busy have we all been in acquiring information in the past one hundred years as to details that few have been able to take the time to attempt to organize thought and to see where we are drifting and what the possibilities of the future are.

The century really opens with the application of steam as a motive power. From a study of a tea kettle boiling vigorously the idea was presented of the use of steam as a motive power. Very crude were the beginnings but by the combination of valves, levers and wheels engines were invented that were able to transmit their power to machinery more effectively than human effort and to-day one man may start an engine which can develop a rated capacity of 40,000 horsepower. Instruments of precision had to be perfected, special tools had to be invented, laws of expansion had to be worked out, new metals and alloys of metals had to be prepared, but there finally have been developed the locomotive for land transportation, huge steamships for ocean transportation, and huge engines and machinery for all kinds of industrial works. The cotton gin was invented to obtain our fiber for clothing, mills were devised for grinding our grain and for the preparation of our foods. Then came the development of the internal combustion engine and the development of automobiles, trucks, and aeroplanes, the latter having now been perfected to a point where they can fly through the air at a speed in excess of 200 miles an hour.

This development in itself called into use the deposits of coal and later the natural deposits of mineral oils and natural gas as fuels from which we get the energy to operate our engines. The materials thus used as a source of energy to propel our engines were derived ultimately from plants which have stored up the energy of the sun in their growth and which have been reserved for us in rather limited amounts in the upper strata of the earth. Where will be the source of our power when these rather limited supplies of material are exhausted is one of the great problems for the future.

From some few simple experiments in flying a kite in a thunder storm and charging a leyden jar from an electric current transmitted from the clouds the observation was made of the similarity of electricity from different sources and an impetus was given to the study of electricity as a possible form of power. Through various studies and inventions it has been found possible to generate the electric current and to utilize its powers in the operation of great machines rivaling in power and in cost the steam engine and in developing methods for the instantaneous transmission of thought that far outrival the possibility of the steam engine.

The invention of the electric telegraph, the laying of the first Atlantic cable, and the more recent invention of the wireless telephone and telegraph have made the instantaneous transmission of thought possible throughout the United States and throughout the world. Recently when the President addressed a joint session of Congress it was possible for thousands of people to hear his speech, to catch the inflection of his voice through telephones, in all parts of the United States. To-day we have market reports sent out daily to thousands of farmers throughout the country; we have reports of sea disasters as the events are occurring and the events throughout the world as they are taking place, but this is a small part of our story and only the spectacular achievements of scientific thought.

Just before and just after the beginning of the 19th century the chemists made their first great discoveries of chemical elements. First came Priestley with his discovery of oxygen gas in 1774. He had noted three years earlier that plants affect the air in a confined space in a different way from animals and that the air which had become vitiated by animals could be revivified by plants. Lavoisier then studied the nature and constitution of carbon dioxide which is given off by animals in their breathing and which is taken up by plants as the principal source of their carbon. In taking in the carbon dioxide and utilizing the carbon the plants return to the air the oxygen which is utilized by the animal. Thus was revealed an interdependence of animal and of vegetable life and the source of the principal material of the growing plant.

Cavendish then made an exhaustive study into the composition of air. He also discovered the element hydrogen. Davy then discovered potassium in 1808 and thus was started the remarkable series of investigations that have resulted up to the present time in discovering something over eighty chemical elements which compose the materials of the earth and of the planetary system. This work involved the making of chemical appliances of great precision, and study of the laws of chemical combinations. In 1828 Wöhler succeeded in the synthesis of urea proving that organic materials could be produced without the aid of living organisms. This gave birth to the important field of organic chemistry which has developed into an enormous field of industrial activities.

With the discovery of the so-called X-ray, which penetrates most substances which are opaque to ordinary light, and the discovery of radium with its emanations, the chemists and physicists of to-day have been enabled to study the atom, the molecule and the structure of the crystal. The perfection of the compound microscope and the ultra-microscope have made it possible to study material things and the constitution of matter. The atom has now been divided into several parts. The origin of electricity seems to be about to be divulged. The enormous energy of the atom and its several parts have been shown. The energy in a drop of water, if it could be utilized, developed and controlled by man, is thought to be sufficient to drive our most powerful engines. Is this the direction that we must look for the future of our mechanical work? The future only can tell where we will get our energy when our coal and oil deposits are exhausted. Scientists are beginning to realize faintly the possibilities in this direction.

Through the invention of the spectroscope and the study of light dispersed as in the rainbow it has been possible to determine the chemical composition of many materials of the earth where the amounts are too small for gravimetric measurements as well as to determine the chemical composition of the sun and of many of the stars where the material is too far away to obtain for gravimetric analysis.

Electricity has been developed for lighting and heating purposes and for many operations in industrial lines.

During the past century the classification of plants has been brought to a high state of perfection, the study of physiological botany has developed many of the life processes of the plant, the study of morphology, the cellular structure, the growth and function of the cells and parts of cells, and particularly the study of unicellular bodies of both plants and animals including bacteria, yeasts, and fungi have revealed many of the mysteries of growth and of disease. The invention of modern photography and moving pictures has done much to reveal the secrets of nature and to record in an accurate way facts that would otherwise be forgotten and the significance of which can not otherwise be successfully understood. The feeding of plants, their acquisition of carbon dioxide from the atmosphere, the part played by water and by mineral substances have been partially revealed. The development of plants through breeding, grafting and hybridization has been studied with fair success and the immunizing of plants to disease and insect pests has progressed.

In the field of medicine and surgery great strides have been taken. The discovery of vaccines, of anesthetics, of toxines, and antitoxines, the formulation of the germ theory of disease, the tracing of certain diseases to insect carriers, the study of cell growth and the possibility of cellular unions in the growth of grafted parts, the successful treatment of wounds through sterilization and perfect cleanliness, the study of hygiene and of the diet, of exercises, and the effects of environment, rest and suggestion and finally the recognition of preventive medicine have unlocked many of the mysteries of life and have thrown the great burden of responsibility on the people.

With all this advance in human knowledge has come the possibility and the necessity for organization, the development of industries and of commerce, of organization of labor and capital. With quick transportation of things and of ideas has come a quick and sudden development in our systems of business organization, of bookkeeping, of exchange and of credits. We have great printing presses that are flooding the world with information in the form of books, newspapers, magazines and circulars. We have great educational institutions superimposed upon a system of compulsory education through the lower grades of training. We have a vast number of research laboratories delving into the secrets of nature; we have a great number of experiment stations trying out methods and testing materials and ideas; we have extension services of all kinds to carry the results of learning and of research to all classes of people; we have hospitals and medical schools for the study and treatment of disease; and we have industrial schools for the training of all classes of mechanics.

All of these things were unknown to the ancients. All have been acquired substantially in the past one hundred years. They all have a bearing upon agriculture and upon the soil. It is just as necessary for us to have these things in mind, the progress that has been made in the past century in the natural sciences, in inventions and in business — all unknown to the ancients — as it was necessary for us to have in mind the wars and political changes that affected those countries in order to understand the development of agriculture and the history of the endurance of the soil.

The world has a new start, through the knowledge of the laws and mysteries of nature revealed to us in the past century. This is but a short period compared with the length of time over which we have traveled in our study of the life of man on the earth and the use of soils. We have no reason to believe that we have exhausted the possibilities of research. On the contrary, there is every reason to think that we have merely made a beginning. The study of the laws of health and of disease has resulted in the inception of a school of preventive medicine so far as relates to mankind that will be a real achievement of world-wide benefit.

The modern concept of the soil, as outlined in the first part of this book, presenting it as an organized thing with functional activities, appears to be a real beginning on a wide and comprehensive basis for the future study of soils and soil control. The first chapter of this book treats of the man and his relation to the soil and his responsibility for the upkeep of soil productivity. The history of Mesopotamia, of Asia Minor, of China, shows that the man is the important factor. The Roman writers show clearly that they recognize the man, his foresight, his insight and his intelligence as the controlling factor in the upkeep of the soil. They were neither misled nor discouraged in the failure of the individual. Where one failed through ignorance or indifference they were supremely satisfied that the master mind could succeed.

With the great facts of the world's history brought forward it is for us to take a hopeful view. We must not fear the failure of tenants, of people who have no personal interest in their lands, or of ignorant people without supervision. These are matters pertaining to human nature. That a tenant may run the productivity down through injudicious and careless methods so that the soil becomes relatively unproductive must not be looked upon as a dispensation of nature or as due to a loss of plant food. The real cause must be appreciated in that the man has failed, through ignorance or cupidity, to maintain the soil in a proper condition for succeeding generations. Such things are not fundamental so far as the soil is concerned, however fundamental they may be as regards the disposition and life of the man himself or of the community. The soil may be abused but it waits patiently for the time when under intelligent care it may blossom forth again in all its glory, fruitfulness and strength.

Do not let us be misled as the ancients were with their tales of mythology. Do not let us be misled with tales of former high yields. We have had such rumors even as regards our own country, but the cold facts or records do not bear out these tales of extraordinary yields. Fortunately in the past 50 years statistical science has been applied to the yield of crops. It has been found that the yield of crops in England and Germany has been gradually increasing during the past 300 years. It has been shown that the yields of wheat and corn in this country have been steadily increasing through better methods of cultivation. Let us hope that these statistical records, as time goes on, will record still further increases and that we shall have more definite knowledge in the future than we have of the past to judge of soil progress. This is the only safe basis upon which the development of the world's agriculture can be measured, but we must not expect a rapid or great development in a few years when we consider the thousands of years that have passed since historic times began.

The period of the agricultural renaissance has been completed, the world has taken a new stand, has acquired new responsibilities with increasing knowledge; we are graduating from a great school of education. Knowing more can we do more in the future than the ancients did in the past? Will we be able to do more through force of mind and of intellect with this newly acquired knowledge and forces than they did without this knowledge and by human labor alone? That we have not done more to increase productivity of the soil in the past century is not surprising. We have concerned ourselves of necessity with details and in acquiring information. It is no more surprising than that the investigations in medicine and in surgery have not noticeably and markedly prolonged the span of human life. It is only within the past year or two that the study of the laws of health and of disease has resulted in the inception of a school of preventive medicine so far as relates to mankind — a real achievement of world-wide benefit. The physician and surgeon have up to now absorbed themselves in the studies of details of the parts rather than of the whole. The time is apparently coming when they will be prepared to study the man as a whole and as a mass rather than as individuals and parts of individuals. The time has come when we who have acquired this knowledge, this insight into the properties and laws of nature and into the functions of the soil types, must ask ourselves, as we ask the young man who is graduating from college and thus has prepared himself to acquire education, what will we do with it?

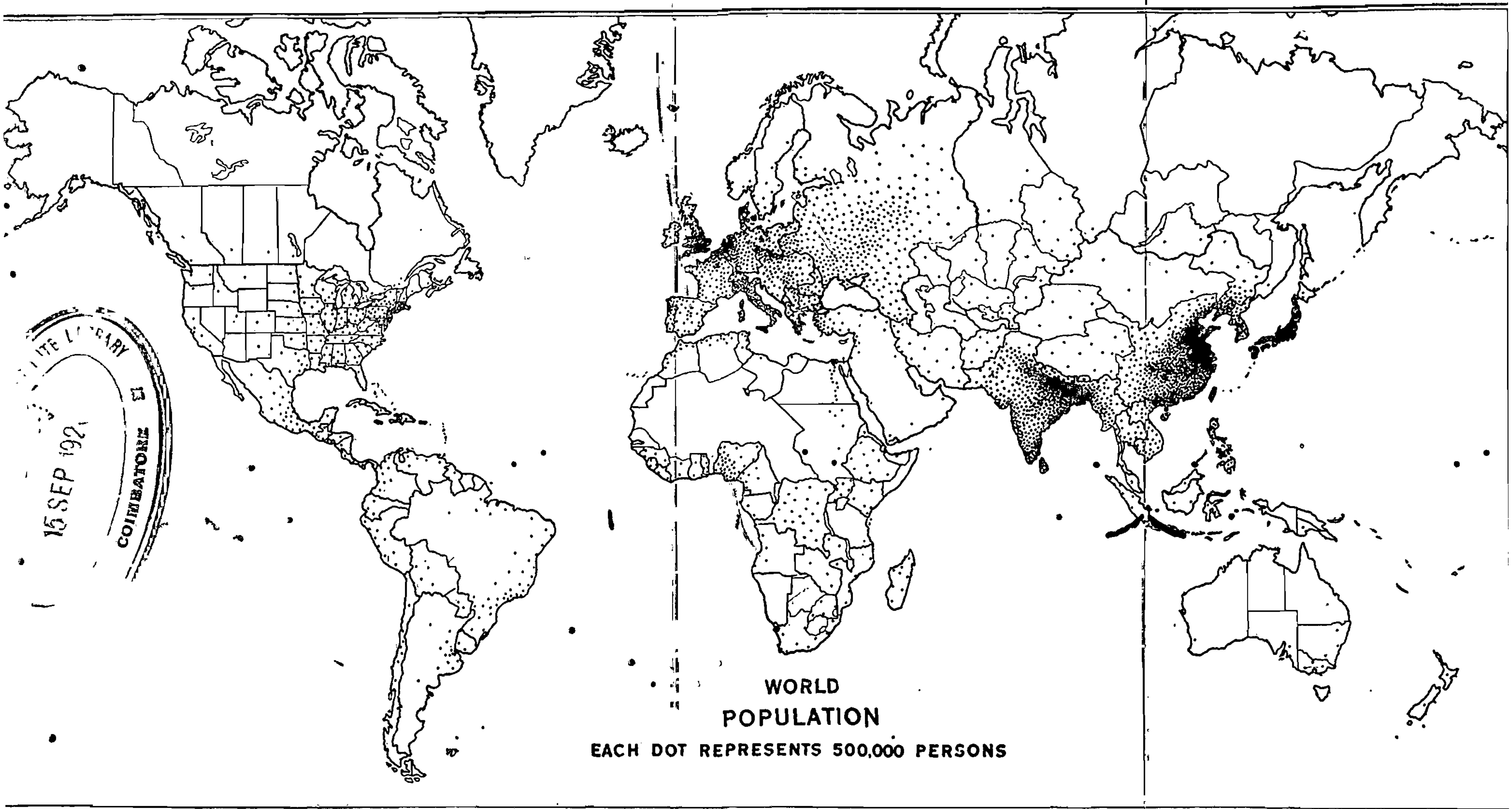


FIG. 31. The population of the world at the beginning of the twentieth century. By V. C. Finch and O. E. Baker.

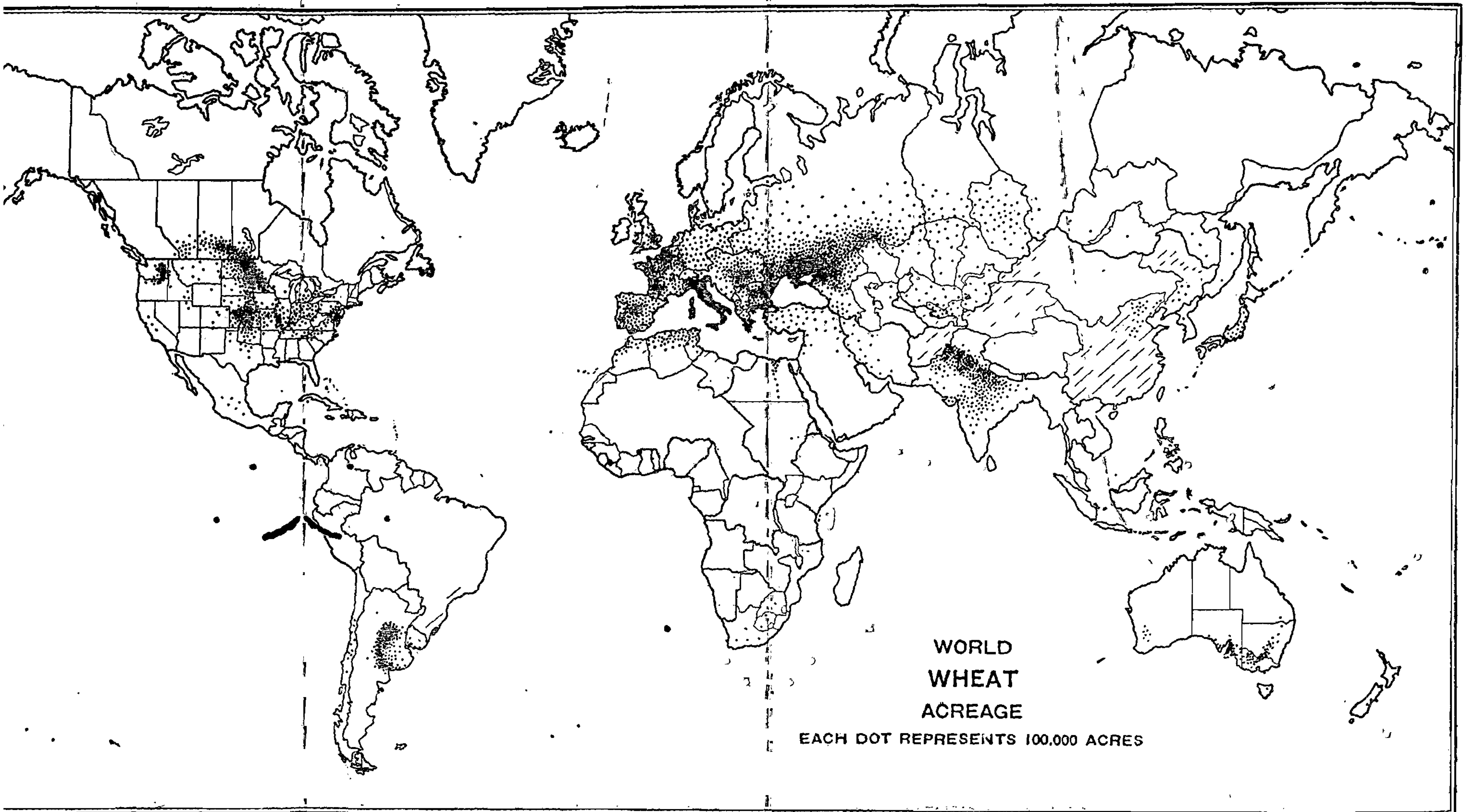


Fig. 32. The acreage of wheat of the world at the beginning of the twentieth century. By V. C. Finch and O. E. Baker.

CHAPTER VIII

WHAT OF THE FUTURE?

WE did not mean in closing the last chapter to imply that our education is complete. The young man, when he leaves college, is only fitted to begin his education, — his real education comes when he enters the world and is finished only when he lays down his life. The college gives him the groundwork, it fits him to acquire real education. So the experience the world has come through in the past century has been a groundwork, a foundation, a basal education. So far as the soil is concerned we see it as a functional body, as a thing that will respond to human endeavor. We see it as the soil and are not disturbed by the glamour and the shimmering of its different parts. The parts are necessary, each part must be understood, but the soil as an entity, the soil type as an individual, is now to be treated as though it were a living thing cared for and developed for the greatest use of mankind.

We are not going to make any prophecies as to future development of agriculture. If we should it would be like the graduating exercises of a young man leaving his college and dreaming his dream of the future of his classmates and himself without the knowledge or the power to do more than to dream of a future into the realms, mysteries and dangers of which the mind can only see for an infinitely short distance, when measured in terms of the history of life, of human endeavor, of countries and of nature.

Before going further turn to the map showing the density of population of the world at the beginning of the 20th century and the map showing the wheat production of the world. If we had such maps showing conditions 20 centuries ago and for each 20 centuries before what a world of information we would have. But looking forward, what will these maps look like if compiled 20 centuries from now. Has the world now reached its limit of population and of production? What if New York, London, China and Japan are overcrowded? They seem small and local conditions when shown on the map of the world. What of northern Asia, of northern North America, of South America, of Africa, of Australia? With our insight into the laws of nature, with our inventions, our annihilation of space,

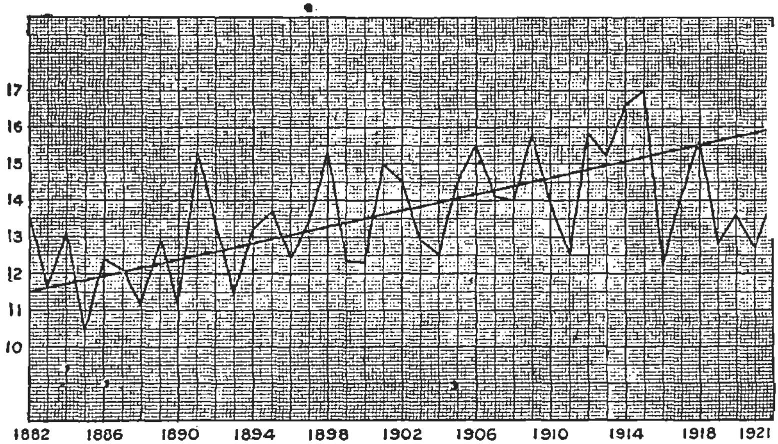


Fig. 30. The average yield of wheat in the United States for forty-one years.

will we allow climate, disease and deserts to impede our progress in the full settlement and utilization of the soils of the world? Will the passions of men, the jealousies and wars of nations and the conflicts of religions cause a curtain to descend as has happened once in historic times — 2000 years ago and perhaps more than once in pre-historic times — before the ultimate destiny of mankind is fulfilled and the whole world becomes fairly populated?

One of the things that will surely be done is the extension of the soil survey and soil classification throughout the world. A beginning was made by the Chinese, over 4000 years ago as already stated and throughout their history they have been blindly groping for a basis of classification without the knowledge we possess of the principles of soil properties. The Greeks and the Romans felt this need as a basis for the most profitable distribution of their crops and as a basis for their agricultural development. When we know these facts what is to be done with them?

King asserts that on his trip in one of the provinces of China he saw a number of fields in different places where he assures us the yield of wheat was at least 117 bushels per acre. Is this a yield that we should work towards? Is this a yield than can be very generally attained on even the best wheat lands of the world? Is this a yield that we may hope to attain on any considerable part of the soils of England or of the United States? Again King says that these yields were obtained by Chinese farmers and from what was said one would imply that they were farmers of average intelligence, that they had done this by their skill and energy and without more than a superficial knowledge, if any, of the great advance in learning of the past century. Does this, therefore, mark the limit of the capacity to produce wheat when we really begin to strive intelligently to develop the largest possible growth?

Sixty or seventy years ago German investigators showed that it was possible by the use of well water or artificial liquid cultures to produce crops three or four times larger than are produced in the soils of the field. Have we reached the limit of wheat production when we harvest 40 or 50 bushels per acre? Have we ever fully developed the capacity of a soil to produce wheat, or have we ever developed a wheat plant to its fullest capacity to develop?

Pliny says, "The procurator of the late Emperor Augustus sent him from that place — a fact almost beyond belief — little short of 400 shoots all springing from a single grain; and we have still in existence his letters on the subject. In a similar manner too, the procurator of Nero sent him 360 stalks all issuing from a single grain." Such a wonder could well be sent to an emperor. Was this a fact or a fable? Was it one of those extravagant statements that Pliny and the earlier writers constantly bring into their stories to lighten up their subjects and inspire the imagination, or does it in fact mark for us a possibility which we may strive for in the future?

The Chinese very commonly raise three or four crops in the same season on the same ground. Some crops they grow together as we produce clover and timothy and yet they seem to keep their soils in a better condition than where a single crop is grown every year. Is there a suggestion here for us?

The Chinese raise more per acre than is raised in the United States but we raise more per man than they do. Can we accomplish the same results with less labor than they require?

We have seen that modern engineers report that the agriculture of Asia Minor, Syria and Mesopotamia, now veritable waste places, can be restored by engineering works, and for years the possibility has been considered of reclaiming for agriculture, through vast engineering works, the great desert of the Sahara.

No one doubts that when the opportunity arises and when food is needed the vast plains and tablelands of South America can be claimed for agricultural production. A few people believe that it may be possible, when the exact classification of soils has been made of northern Europe and of America, that the orderly and intelligent use of the better types of soil and the development of new crops and new industries upon the poorer types (so far as our present limited number of crops are concerned), that all of the waste places can be made to produce some useful thing that will contribute equally to the welfare of man as our better soils are now producing. The only thing we can say now is that we do not understand the problem. But with the advantage of our recent education, are we to put our final stamp of disapproval and close the account forever?

It has been stated that the island of Japan, densely crowded with people, has nearly as much land possible of reclamation as is now under cultivation. These lands lie with a slope of not exceeding 15 degrees. They are wet, stiff and cold. The

Japanese have shunned these lands as if they were a curse, but they have come to realize the possibility of reclamation and they are bravely starting to take up the Herculean task. They have stood and watched these lands for 4000 years. They dread the task now beyond expression as it is so foreign to the habits of life on the soils they have regulated and understand so thoroughly. But they have at last awakened to the possibilities and necessities and are bravely facing the unknown dangers that nature has interposed to their complete settlement of the lowland portion of their island.

The Germans have some 60,000 square miles of organic soils that they have been trying to understand and control. The excess of population of that country has gone out into all the countries of the globe, but as yet that dark spot persists at home and people shun it as though there were a curse on the ground.

Our own Great Plains in the West, the desert parts of our country—when the time comes, when our population has increased, are we going to continue to shun these dark spots or are we going to use the knowledge that we have acquired in the past century and are we going to face these natural barriers, try to understand the mysteries of nature, and project our force against the forces of nature with a determination and a will to succeed? If we had only the information of the ancients we should wisely shun them as they did, but our responsibilities are greater on account of the education we have received in the past century, on account of the veil that we have been able to lift on the mysteries of nature which they claimed only in their early mythology.

The Chinese have maintained their yields by force of necessity with the hardest kind of manual labor. Mesopotamia has lost her yields because her people were driven out and completely destroyed and their irrigation works, which were the basis of their agriculture, were destroyed for lack of appreciation and care on the part of their conquerors. Are we, with our splendid education, with the mysteries of nature that are unfolding to us, going to accomplish by human intellect as much or more than the older countries of the world accomplished by mere human endeavor spurred on by the force of necessity?

Could anyone prophesy as to what is to be accomplished in the future? Could any one put a limit to the achievements if we keep true to our faith with the application of real science to agriculture? We have seen the development of animals — powerful horses, huge meat animals, productive cows and chickens; we have seen the development of our orchard fruits, of our garden vegetables, but we have not yet seen any equal development in our heavy farm crops, wheat and rice the principal vegetable foods of man, corn and oats the principal foods of live stock, or cotton the principal vegetable fiber for clothing.

In closing and in reviewing the life of man so far as we have historical facts the future seems most hopeful, the soil seems to be awaiting our pleasure. Our knowledge has been recently vastly increased. It remains for man to go boldly forward with the best equipment possible, with a constant assurance that he can win if he will and that, while no one can tell what he can do or how long it will take to accomplish things, his best armor both defensive and offensive against the inscrutable laws of nature is the application of science to agriculture.

INDEX