GREEN MANURING

PRINCIPLES AND PRACTICE

BY

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TO THE MEMORY OF MY MATERNAL
GRANDFATHER, AART VAN ZWALUWENBURG,
A FARMER OF THE NETHERLANDS, WHO
LEFT AN OLD COUNTRY FOR A NEW, THAT
HIS DESCENDANTS MIGHT ENJOY THE
BENEFITS OF GREATER OPPORTUNITIES

PREFACE

AGRICULTURE has been, and as far as can now be foreseen, always will be, the basic industry of the human race. Men must be fed even though they have to do without luxuries. Some recent writers have viewed the race between population increase and food supplies with alarm; others have voiced the thoughtless optimism of ignorance. Neither extreme view is warranted. Mankind will adjust itself to new conditions as they arise, but in order to do so with the least suffering, it is necessary that every avenue of approach to the problem of maintaining or increasing the productive power of the soil be investigated. It is because the writer is strongly of the opinion that the practice of green manuring is one of these avenues, and an important one, that he has been glad of the opportunity to bring together what is known about green manuring. The writer is a compiler rather than an original worker in this field, but if his efforts shall result in fostering some interest among those in charge of agricultural research, he will feel well repaid. The future of our country depends first upon an adequate supply of food, and no other body of men has so much need for long vision as those entrusted with the duty of making certain that the generations of the twenty-first century shall not go hungry.

The value of green manuring lies in the fact that organic matter is worked into the soil and the organic matter in soil is recognized as being one of its most valuable constituents. The soil nitrogen is associated with the organic matter and the decay of this organic matter influences the availability of the soil minerals. For these reasons, it has seemed advisable to discuss the amount of organic matter in soils, its source, and the influences which operate for the destruction of or the increase of organic matter, as well as the part it plays in the soil. Such a discussion is a necessary preliminary to the study of green manuring. For this material the writer has drawn freely upon the standard texts on soils, and on original papers. This matter is presented in Chapter III, and in Chapters IV and V are given a brief survey of the nitrogen problem and nitrogen fixation, all preliminary to the more special consideration of green manure crops, their composition, decomposition and use.

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THE writer has received help from so many friends that individual acknowledgment is impossible. He trusts that this general expression of his deep sense of obligation will reach all those to whom he is indebted. He wishes, however, to make special acknowledgment of help received from his wife in critical reading, and from three friends, Mr. L. W. Kephart, for photographs and in the preparation of graphs; Mr. E. A. Hollo-well, for help in the preparation of tables and in various calculations; and Miss Mary R. Burr for critical reading, for the checking and the preparation of the bibliography and for invaluable help in proofreading and preparation of the index.

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CHAPTER I

INTRODUCTION

GREEN manuring has been an agricultural practice among European farmers for more than two thousand years, but not until the nineteenth century did students of agriculture become interested in the processes by which plant material turned under became available for subsequent crops. Most of our scientific knowledge of plant nutrition, of the microörganisms of the soil, and of their importance in soil fertility has accumulated during the nineteenth and twentieth centuries. It was during the nineteenth century, too, that the tremendous expansion of world food supplies took place, so that the available food of the world increased more rapidly than the population, and seemed to many to prove the fallacy of the Malthusian doctrine. In passing, attention may be called to the fact that "the law of Malthus has been often repudiated but never refuted." Recent writers have made it clear that the end of this rapid expansion of food supplies is not far off, if indeed, the peak has not already been reached, and that it is time for men to take thought of the situation and consider what may be done to provide for an ever-increasing population. In the United States practically all of the good land, land that merely requires a reasonable rotation to maintain yields, is already in use and cannot be depended on for very large increases. Many millions of acres of the poorer lands are either not in use or yield small returns, and it is by increasing the yields of these poorer lands that we must look for a part of the increased food supplies this country will use within the next fifty years.

Food Supply and Population.—The general problem of the relation between food supply and population has various phases, some of the more important of which are production, transportation, economics of marketing, and control of population increase. A century ago, transportation was relatively more important than production. There was often famine in one region and plenty of food in another, but with no means of bringing the food to the hungry. To-day transportation, except as a part of the economics of marketing, is not of such great importance, since that part of the general problem has been solved, and at present the economics of marketing is receiving most attention. Farmers, especially in the United States, find it, at present, not difficult to produce more than the market will absorb. Production is, however, the fundamental problem and it is a safe prediction that in a hundred years the production of more food per acre, and the utilization of every acre of land will be matters of concern.

During the past few years statisticians have displayed interest in the problems of population increase and food supply, and various government agencies in the problem of land utilization. While all of these matters are somewhat speculative, two facts stand out clearly; there is a saturation point for population, and this saturation point is closely connected with land utilization. While of the total land area of the United States, 1,769,000,000 acres, including forest land, are actually or potentially available for agriculture, nearly one-third of this is arid or semi-arid pasture and range. With the exception of a small amount of potentially irrigable land and of good land that may be reclaimed by drainage, all the good land in the United States is now being used for cropping or for pasture. This fact, together with our steadily increasing population, has led Gray * and others to study the various possibilities by which a greater total production of foodstuffs might be insured. For the most part, such increase must be accompanied by increased prices or must be stimulated by them, because increased production can no longer be had by cropping new and fertile land as in the past, but must be secured, if at all, by the better utilization of land now in use and more especially by increasing the yields of the poorer lands. So long as the better lands can supply the demand, those lands that yield less will not be pressed into full service; but the time is rapidly approaching when the demand for foodstuffs will make it profitable to do what may be done to get fair yields from the poorer lands. Statisticians are not in agreement as to the trend of population increase and food supplies. Some believe that by 1950 the population of the United States may reach 150,000,000 and that to accommodate such a population the increased food supplies required will demand, not only that all possible irrigable and drainable land be used, but that there shall be an increased production on the land now in use. Others point to the lessening rate of increase of population and are hopeful that means may be found to feed the probable increase of population for many years to come. The population of the United States, however, is by no means stationary, and whether the saturation point be reached in fifty years or in a century, it must be clear to every student of agriculture that the time will come when, if we are to maintain our present standards of living, there must be an ever-increasing production of food. Since only a small part of this increase can come from newly reclaimed lands, a large part must come from increased production on the lands at present in use. Baker has estimated that if the yields of our principal crops, except corn and cotton, could be

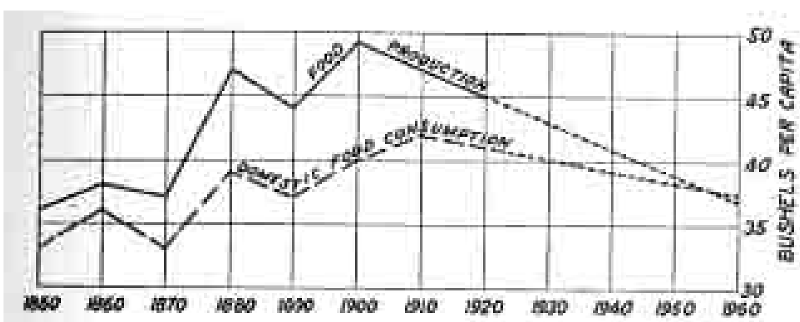

FIG. 1.—Graph illustrating the relation between food production and domestic consumption in the United States. The portions of the lines at the right show the course these curves will take if the conditions for the years 1910 to 1920 continue to prevail.

From the Geographical Review 3. 1923. The American Geographical Society, N. Y. (Redrawn and extended from 1920 to 1960 by L. W. Kephart.)

increased to the yields secured in Germany, our agricultural production would be increased 33 per cent, and that if this increase could be secured on our present area of arable land, agricultural products could be raised to feed 166,000,000 people. Gray and others have pointed out that, with no change in consumption or in per acre production, it will not be possible to feed the 150,000,000 expected to inhabit this country in the near future.

* A bibliography of text references will be found on p. 325. When more than one title is credited to the same author, or authors, a number in the text indicates the title to which reference is made.

As shown by the curves in Fig. 1, the margin between food production and domestic consumption has narrowed since 1900, and, at the present rates of production and consumption, will have very nearly disappeared in another quarter century. Doubtless increased production and decreased consumption, both under the stimulus of higher prices, will delay the time when domestic consumption overtakes production, but unless production is increased consumption will, sooner or later, have to be materially diminished.

Increased Yields Important.—While it seems possible to increase the average production of corn on our fair to good lands by 25 per cent and to do this economically, and while it is certainly possible by adequate means to increase the production on the poorer lands to a greater degree, it may be doubted whether production can be increased to the German level, at least on much of our arable land. As Gray has pointed out, various methods of adjustment to the conditions produced by the increasing density of population will doubtless take place. It is clear, however, that every acre must be made to yield to its full capacity. Every possible means must be taken to increase yields. Many million acres of the poorer lands in the East and South are idle or are cropped only ones in several years because, at present prices of agricultural products, the returns do not warrant the expense in labor and fertilizers necessary to make them productive. At the same time, land in parts of the semi-arid belt is becoming less productive because of the gradual destruction of the humus by cropping. With the advance in prices of farm products that may be expected to follow the increase in population from the 105,710,620 in 1920 to 150,000,000, the poorer lands will be brought into use and the yields from these lands will depend primarily on the organic matter in them. Fertilizers will be necessary, but the full benefit from fertilizers is realized only on land reasonably well supplied with organic matter. The problem before the man who farms the poor lands of the Atlantic seaboard and the one on the wheat lands of eastern Washington is in one respect the same—the increase of organic matter in the soil. One way to accomplish this is by green manuring. By this it is not meant that green manuring will solve the production problems of the future, but that it is one of the methods by which the productive power of a soil may be increased or maintained. Green manuring will take its place beside tillage, crop rotation, improved varieties, and the use of fertilizers, and, especially in the eastern United States, will come into more general use than is the case to-day. It should be added that there are, of course, many thousands of acres of poor lands that would better be devoted to forest growth than to cropping. While even very poor lands have been improved by green manuring and the liberal application of fertilizers, such treatment is only rarely profitable, as when access to great markets affords opportunity to dispose of high-value crops. Forest products will always be needed in large volume and most of the very poor land, steep and stony hills and other land of low value, can be more advantageously planted to permanent forest than cropped.

In the effort to maintain the food supply for an ever-increasing population, every possible means will eventually have to be utilized, and even then, as East has said, "all increase will be temporary, and even current production can not be maintained, unless the essential elements of soil fertility are conserved by every method possible." One of these essential elements is organic matter.

At present, the larger part of the vegetable products produced in the United States are fed to animals, only 24 per cent being utilized directly as human food. As population increases, there will probably be a change in this respect; more crops will be consumed directly by the human population, since, on a given area, larger numbers can be sustained in that way. But this will mean a decrease in the number of cattle and, consequently, in the supply of stable manure. The continuing and probably increasing demand of the soil for organic matter will then inevitably lead to the greater use of green manures.

Soil Deterioration.—Recently there has been some discussion of "soil deterioration," but, as is so often the case, much of the difference of opinion expressed appears to be due to a lack of an exact definition of the terms used. One writer attempts to show by statistics of crop yields that soils do not deteriorate, but this method disregards the fact that crop yields are influenced by farming methods and improvements in varieties used as well as by the changing soil conditions. Another [343] shows that the longest continuous cropping tests recorded indicate that, without any soil treatment other than cropping, yields have decreased. So far as data are available they show that the mineral elements of the soil, those derived from the original rock fragments, do not decrease so as to warrant the conclusion that soils deteriorate; but a soil is more than an aggregate of rock fragments. The organic matter in soils is an essential constituent, and not only is this subject to loss but this very loss is essential to the productivity of the soil. "It is the changing organic matter that makes for soil fertility, not the mere presence or store in the soil." [250] That this organic matter, and with it the soil nitrogen, is quickly lost by cropping will be shown in a later chapter, and it is to the change in soils that results from this loss of organic matter that the term "soil deterioration" should be applied. Under improper cropping methods "soil deterioration" is a real and dangerous phenomenon, but such deterioration can be prevented and crop yields increased by proper farming methods. "It is only by continually supplying organic matter that the soil forming, soil-fertility promoting, dynamic changes can continue to go on unchecked and undiminished, liberating ammonia and other compounds, supplying energy for bacterial life and furthering nitrification and nitrogen fixation." [250]

The experience of centuries in China, Japan, and Italy, and the more recent experiences in Germany and in parts of the United States, notably in the Southeastern States, have shown that green manuring can maintain or increase the productive power of soils, whether naturally poor or worn out by injudicious cropping.

Definition of Terms.—By green manuring is meant the turning under of a green crop, for the enrichment of the soil. Some German writers have limited this definition to the turning under *of legume* crops, but there seems no warrant for this restriction. Strictly speaking, the green crop must have been produced for the purpose of being turned under. This definition is, however, a very narrow one. Any plant material, whether sod, rye, weeds, clover, cowpeas, or crop residues, when turned under accomplishes the purpose of green manuring, namely, to add organic matter to the soil. This is equally true whether this plant material is green or dry. It is not possible to distinguish sharply green manuring from cover cropping, though each term has a basic meaning of its own. The term "cover crop" was first used by Prof. L. H. Bailey to designate a crop especially planted to cover the ground in winter and to serve as a protection to the roots of trees. When such a cover crop is rye, or clover, and is turned under in spring, it becomes a green-manure crop. Of late in the United States the term "cover crop" has tended to displace the term green-manure crop, so that the two terms have become, to a great degree, synonymous. A "catch crop" may also serve as **a** green-manure crop, and indeed a great deal of green manuring is done with catch crops. It seems necessary, therefore, to point out that, while definitions may be made, the practices carried on under these terms run into or overlap one another and any attempt at sharp separation must be artificial. With this understanding, the following definitions may be given:

> *Green manuring is the practice of enriching the soil by turning under undecomposed plant material (except crop residues), either in place or brought from a distance.*

A cover crop is one planted for the purpose of covering and protecting the ground during winter.

> *A catch crop is a rapidly growing crop, following a main crop during the same season and occupying the ground for a few weeks only.*
>
> *A shade crop is one used in hot regions to shade the ground during summer and thus prevent beating from rains, excessive heating of the soil, or injury to trees from reflected heat.*

Cover crops, catch crops, and shade crops may, and most commonly are, used for green manuring. Again, when a second crop of clover is turned under, the effect is precisely the same as if that crop had been grown for green manure; when sweet clover is seeded in wheat, cut for hay the first season, and turned under for corn the following spring, the sweet clover becomes a green-manure crop. In this book, therefore, the emphasis will be placed on the turning under of plant material for the enrichment of the soil, whether it is done by the growing of special green-manure crops or by allied practices, but the fact will not be lost sight of that green manuring in the strict sense is a special practice having its own place in soil improvement.

Elements Necessary to Plant Growth.—All crop plants require for growth larger or smaller amounts of nitrogen, phosphorus, potassium, calcium, oxygen, hydrogen, sulphur, magnesium, iron, and carbon. These are known as essential elements because in the absence of any of these normal growth does not take place. Of these, oxygen and carbon are taken from the air, but the others reach the plant through the soil or soil solution or in special cases the nitrogen reaches the plant through the help of certain bacteria. Of these elements, nitrogen, phosphorus, and potassium are commonly included in the complete fertilizers, not because they are more necessary than others, but because agricultural experience has shown that these are the elements more often present in insufficient amounts for satisfactory crop growth, or, at least in available form, in insufficient amounts. For many soils it is also necessary to add calcium and cases are known where the addition of magnesium or of sulphur has proved beneficial. To be available to plants, these elements must be in a soluble state, and it sometimes happens that some of these, while present in the soil in abundance, are in such a chemical state as to be insoluble. The solubility of the phosphorus and potassium in the soil is increased by the presence of organic matter, directly through the formation of organic compounds of these elements and indirectly through the action of the carbon dioxide liberated in the decay of organic matter. Of these elements, nitrogen is the one of which the available supply is chiefly affected by green manuring, directly by increasing the amount in soils through legumes and indirectly by making the soil a more favorable medium for the activities of microörganisms.

Organic Matter the Home of Microörganisms.—The nitrogen in soils is nearly always associated with organic matter, the humus of soils being a storehouse of nitrogen which is made available to crops by the action of microörganisms. A good soil is not merely an aggregate of finely ground rock particles, but is one containing an adequate amount of organic matter. This organic matter is the home and food of countless millions of living creatures, bacteria, fungi, algæ, Protozoa, insects, earthworms, each working under the laws of its own being and producing changes in the carbon and nitrogen compounds in the soil. Under suitable conditions of temperature, moisture, and aeration, these activities go on constantly; night and day, organisms are produced, live their life, influence the soil and die, the substance of their bodies being again subject to attack by later generations of organisms. The soil in which plants grow must not be thought of as a layer of dead matter in which plant roots are fastened and from which they draw such substances as they need for growth, but rather as a very busy chemical and biological laboratory. Crop plants take their carbon from the carbon dioxide of the air but most soil organisms depend on the carbon compounds in the organic matter of the soil. This furnishes the energy for their life processes, and large amounts of carbon compounds mean an increase in the number of microörganisms, provided always that there is enough available nitrogen to support the larger numbers. Oxygen is essential, not only to the life processes of both higher and lower organisms, but to certain processes by which compounds are. changed by microörganisms. Most of the elements needed by crop plants are, therefore, needed by the soil organisms as well, and to a degree the latter compete with the former for food. The soil Protozoa again feed on the bacteria, many of which carry on functions useful to crop plants. Insofar as these Protozoa keep down the numbers of useful organisms, they may constitute a danger to the cultivator of the soil, but in the end their bodies, too, add to the nitrogen available for crop plants.

The end result of all this complex of interactions, of biological and chemical processes, of the competition between different forms of life, is a sufficient or an insufficient supply of food material for crop plants, and in some cases, the production of harmful toxic substances.

Man Cannot Change Natural Law but Can Take Advantage of Favorable Processes.—While man is powerless to affect in any way the laws of nature, he can, by taking thought of the processes going on, so adapt his own practices as to benefit by those natural processes that are useful and avoid in a measure those that are harmful to his crop plants. Agriculture is based on this fact. In early days, green manuring was practiced because it was found to produce better crops; to-day, much is known of what goes on in the soil when organic matter is added, but much still remains to be learned. It is known that soil organisms cause the breaking down of the complex substances in plants which are turned under and that ultimately these substances are reduced, or changed, to forms which growing plants can use. If no crops are ready to use the nitrogen, when this is in available form, it is leached out of the soil and lost, or it may be utilized in part by fungi and bacteria and so revert temporarily to insoluble organic nitrogen. An ideal system, therefore, would be one in which enough nitrogen could be made available, but not more than could be immediately taken up by growing plants. This ideal will probably never be realized, but as far as the nitrogen problem is concerned, cropping systems should be so arranged as to approach the ideal as nearly as possible. When organic matter is turned into the soil, those portions most readily attacked by soil organisms are quickly broken down and in part made available to the season's crop. The more refractory portions are only partially broken down and become a part of the more or less permanent soil organic matter or humus.

While all the chemical elements mentioned above are essential to plant growth, this is also a result of the interaction of many factors: sunlight, moisture, temperature, soil texture, availability of food materials, and presence or absence of injurious substances, not to mention injurious insects and plant diseases. Any one of these may effect a change in any other and, when most conditions are favorable, plants may thrive in spite of the fact that some are unfavorable. In the Ohio River Valley, red clover will not thrive in soil with a lime requirement of more than about 1000 pounds per acre, but under less trying climatic conditions and with plenty of phosphate, it has been known to grow luxuriantly in soils with a lime requirement of 1500 pounds per acre. While man cannot change climate and can regulate the water supply to a very limited degree only, he can, to a large extent, control soil conditions by adding food materials when necessary and by improving tilth. It is important that those conditions that can be controlled be made as favorable as possible in order to minimize, so far as may be, the unfavorable effect of conditions that cannot be controlled.

SUMMARY

With gradual increase of population, the question of adequate food supplies and, consequently, the utilization and increased productivity of all arable land will become ever more urgent. While green manuring is not the only method for increasing soil productivity, it is an important one.

The terms to be used have been defined and it has been pointed out that the practices described by these terms overlap one another. A given crop is often used for more than one purpose.

Nitrogen is the food element chiefly supplied by green manuring, since nearly all the soil nitrogen is associated with organic matter and the supply of nitrogen can be increased by turning under legumes.

Decomposing organic matter is the home of millions of microörganisms, and it is through the activities of these minute living things that nitrogen is made available to crop plants.

CHAPTER II

HISTORY OF GREEN MANURING

GREEN manuring played an important part in the agriculture of the Greeks and Romans and is an even more ancient practice in China. During the Middle Ages its importance declined in Europe, though the old Roman practices continued in the Mediterranean region. During the nineteenth century, interest in green manuring revived, and at present millions of acres in Europe and America receive annually a green-manure crop.

Green Manuring in China.[1]—The exact date of the beginning of the practice of green manuring in China is obscure. Apparently, the earliest record of the use of grass or weeds as manure is found in the Yueh Ling or fourth book of the Li Ki or Book of Rites, a collection of works of different authorities compiled in the Han dynasty. The exact date of the Yueh Ling is in question, but it is evident in any case that the fertilizing value of grass or weeds had begun to be realized as early as the time of the Chou dynasty. (1134-247 B.C.)

In Ts'i Min Yao Shu of Chia Szu Hsieh who lived about the fifth century B.C., there is a passage which reads: "For manuring the field, lu tou , *(Phaseolus mungo,* L. var. *radiatus,* Bak.) is best, and siao tou, *(P. mungo,* L. var.) and sesame rank second. They are broadcast in the fifth or sixth month, and plowed under in the seventh or eighth month. . . . Their fertilizing value is as good as silkworm excrement and well-rotted farm manure." This is exactly what we now call green manuring.

Wang Chen added to the above description in his Book of Agriculture, which was first published in A.D. 1313. "This process is the common practice in Kiangsu, Anhwei, and farther north." He also introduced the term miao fen to indicate cultivated plants used as manure, and also the term ts'ao fen to indicate weeds and young branches of trees and shrubs used as manure.

Many farmers in Kiangsu Province plant regularly bur (Genge) clover[2] *(Astragalus sinicus,* L.), a leguminous plant, for the purpose of manuring rice fields. And this practice has at least a history of three hundred years and very likely more than that, as it is described in the Nung Ching Ts'uan Shu of Hsu Kwang-ch'i of the early Part of seventeenth century," Herb manuring crops, like bur (Genge) clover and Chinese trumpet-creeper *(Campsis chinensis,* Voss.) are specially planted in Kiang-nan, the Lower Yangtze Basin, for the purpose of manuring fields. These are not wild herbs at all."

In Greece and Rome.—Theophrastus, who died in 287 B.C., says that in parts of Greece, beans *(Viciafaba)* were turned under when in bloom. The Roman writers on agriculture advise planting lupines and beans, especially on thin land. Varro (116-27 B.C.), says "Certain plants are cultivated, not so much for their immediate yield, as with forethought for the coming year, because cut and left lying they improve the land. So if land is too thin, it is the practice to plow in, for manure, lupines not yet

[1] The following notes on the ancient Chinese practice of green manuring have been kindly furnished by Mr. Wan Kwoh-ting of the University of Nanking Research Library, Nanking, China, and are reproduced with minor changes.

[2] Bur clover in the United States is another plant, see p. 224.

podded, and likewise the field bean, if it has not yet ripened so that it is fitting to harvest the beans." Cato, Columella, and Pliny give similar advice.

In Mediaeval Europe.—The Middle Ages produced no agricultural literature, but there is reason to believe that the practice of turning under lupines continued uninterruptedly among the peasantry of Italy and the south of France. Piero de Crescenzi (1724) as quoted by Adam Dickson, says that in Tuscany the expert farmers sow lupines in July and August and in October. "They cut them down with spades and lay them in the furrows. There they sow the grain and cover the seed with the plough. The fields cultivated in this manner produce a plentiful crop next summer. But the Milanese sow radishes thickly, and, when they have grown up, turn them under ground; and others sow lentiles and turn them under ground when they have arrived at their full growth." Kiihn says that since the time of the Romans up to the *present time,* the lupine has been extensively used in Italy and in South France.

In Germany.—Green manuring seems not to have been common among the North European peoples in the early days of the Frankish Empire, for there is no mention of it in the agricultural orders issued by Charlemagne. The three-field system [1] of the Middle Ages had no place for green manuring. However, by the end of the seventeenth century, green manuring was not uncommon in Germany. Kühn quotes v. Hochberg (1701) as follows: "Besides lupines, horse beans were used, and in the neighborhood of Quedlinburg, it is customary to sow peas on far-off fields and, when these begin to bloom, they are plowed under, from which the ground becomes fat and mild." In 1817, Karl v. Wulffen, observing the use of lupines in South France, introduced the lupine on his estates in Germany and, from his estates, the culture of lupines on sandy lands spread widely. Nearly a century before that, Frederick the Great had unsuccessfully urged the culture of lupines for the sandy lands of Prussia. It was, however, Dr. Albert Schultz, of Lupitz (known in German literature as Schultz-Lupitz), who firmly established the use of lupines on the sandy lands of Germany. Nolte calls him the "father of modern green manuring in Germany," and considers his work as second in importance only to that of Liebig (Fig. 2).

[1] In the three-field system one field was in wheat or rye, one in oats or barley or sometimes in beans, and the third lay fallow in preparation for the following year. Each land owner had a right to a certain area of meadow and after harvest all fields were used in common as pasture. There were no cultivated grasses or clovers and there was no way in which a land owner could improve his soil by growing green-manure crops.

FIG. 2.—Dr. Albert Schultz-Lupitz.

(Courtesy German Agricultural Society.)

About the middle of the nineteenth century, the interest in green manuring reached such a height in Germany that some even urged the practice of agriculture without cattle and the use of green manure to replace stable manure. This was, however, found unprofitable on the better, clover-producing lands, but the controversy waged intermittently. Kühn, while strongly approving the practice of green manuring for sandy lands, unqualifiedly condemned the turning under of any leguminous fodder. In this, he was opposed by Wagner,[306] who insisted that there were conditions under which it was better to turn legumes under than to cut and prepare them for feed.

In England.—In England, green manuring was practiced early in the eighteenth century, since Mortimer mentions buckwheat as being turned under for wheat. Adam Dickson says that "in Britain, buckwheat, clover, peas, and other pulse, are sometimes sown, to be plowed in for manure."

In America.—The practice of green manuring was carried from England to the American colonies, but it was not common in the early days. Jared Eliott recognized the value of red clover for improving worn soil and says that "another way of mending land is what they call in England green dressing; this is by sowing buckwheat, oats, or rye, and when it is grown up and is full of sap, they plough it in, after this let it be till fully rotten, then plough again and sow your wheat." Here Eliott is evidently referring to an English practice not yet in use in the colonies.

By the end of the eighteenth century, however, green manuring was practiced to some extent in Maryland and Virginia. Greenway describes the use of a wild plant which he called "Eastern-shore-bean," now known as Partridge pea *(Cassia chamcecrista)* which the farmers turned under for soil improvement, but he admits that it is hot equal to "common cornfield pea" (cowpea), which also appears to have been used at that time for green manuring.

Richard Parkinson seems to be the first who urged the use of cover crops, though he did not use that term. He says " . . . it is seen how earnest my wish is that the surface of the ground should at all times, winter and summer, be well covered, whenever it possibly can be accomplished. Of which the farmer or planter must judge from the circumstances attending the situation of his farm or plantation, and of the manner in which it is to be accomplished."

In the Memoirs of the Philadelphia Society for Promoting Agriculture are found letters between Judge Peters and Col. Taylor of Virginia, in which both men appear impressed with the importance of maintaining the supply of organic matter in the soil. This has not ceased to be a problem to the farmer of the South; indeed, the area over which the problem is acute has steadily widened until to-day all parts of the South and of the Atlantic Seaboard States are struggling with the problem and it is recognized as a serious one even in the semi-arid sections of the West.

Shortly before the middle of the nineteenth century there appears to have been an increased interest in green manuring. Allen says of green manuring, "This system has within a few years been extensively adopted in some of the older settled portions of the United States." The turning under of the second growth of clover for wheat in the North, and the use of cowpeas in the South are mentioned as examples.

In 1856, Reinbold published a curious work in which he advocated the collection of all sorts of wild plants, many of them now considered as among our worst weeds, and the seeding of these so that a dense mixed growth might be secured for turning under. Neither Reinbold nor Wolfinger and associates, however, added anything to our knowledge, and their work is of importance merely as showing that the interest in green-manure crops remained active throughout the early years of the nineteenth century.

In 1876, Harlan published the first edition of a work on green manuring, which subsequently ran through several editions.

History of Green-manure Crops.—With the exception of the horse bean and the lupine, the history of which as green-manure plants dates back to early Greek and Roman days, and in a less conspicuous way that of sweet clover, which first came into prominence as a soil improver, the crops used to-day for green manuring in the United States do not have a long history solely as soil improvers.

Almost without exception, the first recorded use of such crops is as forage or as human food. Only secondarily did they become soil-improving crops. For the most part, the history of our agricultural crops is lost in obscurity; but when alfalfa, clover, cowpeas, soybeans, peas, rye, and other forage and food crops are first heard of, it is in respect to their use as food for man or beast.

SUMMARY

Green manuring is a very ancient farm practice. Its value was understood by the Chinese, perhaps three thousand years ago, and certainly by the Chinese, Greeks, and Romans for an unknown time prior to the birth of Christ.

The practice remained in the countries bordering on the Mediterranean; but among the North European peoples the existence of the three-field system, with its use of all land as common grazing ground after harvest, left no place for green manuring. However, the practice was introduced into Germany, probably toward the end of the seventeenth century. In England, buckwheat was plowed under early in the eighteenth century, but there is no record of legumes having been used in England at that time.

In New England, no special green-manuring crops appear to have been grown up to the middle of the eighteenth century, although the value of clover for soil improvement was recognized; but in Maryland and Virginia, leguminous green-manure crops were grown during the latter part of the eighteenth century.

CHAPTER III

ORGANIC MATTER

THAT organic matter is of great importance in soils has always been recognized. Not only does it carry a store of nitrogen and other elements necessary for the growth of plants, but it influences the physical condition of the soil and thereby promotes root growth. An intelligent appreciation of the use and value of green manures will be facilitated by a knowledge of the role of organic matter in the soil, the way organic matter is lost from or added to the soil, and the relation between these processes and soil microörganisms.

Source of Organic Matter.—The organic matter in soils has its origin in once-living matter. The origin of life is not known, but it is known that the earliest living forms were simple ones and doubtless the first deposits of organic matter came from the dead bodies of microörganisms. Later, and for countless ages before agriculture began, plants were growing on the surface of the earth. These plants produced roots which ultimately decayed, stems, leaves, and flowers, all of which sooner or later fell on the surface and some of which were carried below the surface by various agencies. Darwin has shown how matter of this sort is carried under the soil surface by earthworms, either directly by being dragged into their holes, or indirectly by being covered by their castings. Small animals, as rodents, doubtless have played a part in carrying plant debris below the surface, and to this must be added the organic matter in the bodies of microörganisms, of earthworms, insects, burrowing rodents, all of which, dying, have left their remains to be incorporated with the soil. It seems certain, however, that by far the most important source of organic matter has been plant roots. These, penetrating often to considerable depths and decaying year after year only to be renewed with the advent of another season, have in the course of time left great stores of organic matter to be broken down into humus. The dung of wild animals in past time and the stable manure applied by the farmer have added to the organic matter in the soil, and this is equally true of the crop residues and green manures which the modern farmer turns under (Fig. 3).

Besides these residues from higher plants and animals, the micro-flora and fauna of the soil play a not inconsiderable part. The higher fungi often form great masses of growth, both above and below ground, and the work of recent investigators has shown that fungi and other organisms are extremely numerous in most soils. Lyon and Buckman estimate that the aggregate weight of the microflora may readily be 2000 pounds per acre in the surface soil.

Amount in Soils.—It is difficult to give any figure for the total amount of organic matter in soil, both because the amount in soils varies so greatly and because different workers have not always used the same methods and the same terms in the same tense. The older students of the soil used the term "humus" as synonymous with organic matter and it is still sometimes so used. However, in modern usage, the term "humus" is confined to that part of the organic matter which can be extracted with ammonium hydroxide. This portion has already undergone partial decay and is only a part of the total organic matter. The results secured by the ignition method give higher figures than those secured by other methods.

FIG. 3.—Organic matter is added to the soil by turning under the natural vegetation. Plowing natural sod in Nebraska.

(U. S. Department of Agriculture.)

Thatcher gives the total organic matter and the humus for certain Washington soils as follows:

TABLE I
PERCENTAGE OF ORGANIC MATTER, HUMUS, AND NITROGEN IN SOME WASHINGTON SOILS
(Results of Analyses—Pullman Samples)

Kind of Land	Description of Samples	Organic Matter, Per Cent	Humus, Per Cent	Nitrogen,- Per Cent
Hilltop	Virgin, 1st foot	6.71	2.01	0.143
	Virgin, 2d foot	5.73	0.80	0.080
	Virgin, 3d foot	4.90	0.60	0.064
	Cultivated, 1st foot	6.45	1.77	0.133
	Cultivated, 2d foot	5.48	0.63	0.084
	Cultivated, 3d foot	4.62	0.38	0.043
South slope	Virgin, 1st foot	5.67	1.80	0.155
	Virgin, 2d foot	4.50	1.04	0.088
	Virgin, 3d foot	5.45	0.61	0.065
	Cultivated, 1st foot	5.57	1.52	0.145
	Cultivated, 2d foot	4.35	0.85	0.081
	Cultivated, 3d foot	4.10	0.64	0.045
Bottom land	Virgin, 1st foot	8.13	3.05	0.229
	Virgin, 2d foot	6.71	2.40	0.150
	Virgin, 3d foot	6.17	1.77	0.113
	Virgin, 4th foot	5.42	1.43	0.091
	Cultivated, 1st foot	7.43	2.83	0.221
	Cultivated, 2d foot	6.15	2.09	0.124
	Cultivated, 3d foot	4.93	1.59	0.091
	Cultivated, 4th foot	4.37	1.19	0.072

Alway gives the following figures for Nebraska soils:

TABLE II*
ORGANIC MATTER AND HUMUS CONTENT OF CERTAIN LOESS SOILS OF NEBRASKA

	Semi-arid Soil, Wauneta		Humid Soil, Weeping Water	
	Organic Matter	Humus	Organic Matter	Humus
lst foot	2.77	1.02	4.98	2.34
2d foot	1.38	.65	3.02	1.29
3d foot	1.09	.48	1.38	.55
4th foot	.79	.34	.83	.26
5th foot	.55	.26	.45	.23
6th foot	.45	.26	.36	.19

* Rearranged from Lyon and Buckman, Nature and Properties of Soils (copyrighted), Table 27. By permission of The Macmillan Co.

It is evident from these tables that the humus content is in general only one-half, and often much less than one-half of the total organic matter.

The varying results secured by the use of different methods of analysis are shown in Table III, from Lyon and Buckman, after Wiley.

TABLE III
VARIATION IN PERCENTAGES OF ORGANIC MATTER IN SOILS AS FOUND BY DIFFERENT METHODS

Soil	Ignition	Combustion (C x 1.724)	Chromic Acid (C x 1.724)
Old pasture	9.27	6.12	4.84
New pasture	7.07	4.16	3.32
Arable soil	5.95	2.44	2.03

* From Lyon and Buckman, Nature and Properties of Soils (copyrighted). By permission of The Macmillan Co.

Here again, it is clear that the percentage of organic matter as determined by one method may be more than double that as determined by another method.

Cameron gives the results of the analyses of 1340 samples of surface soil and 1220 samples of subsoil, all of the analyses having been made by the chromic-acid method. The average organic matter was found to be 2.06 per cent for surface and 0.83 per cent for subsoils. Lyon and Buckman give the organic matter in a number of soils as follows:

TABLE IV *
PERCENTAGE OF ORGANIC MATTER (C x 1.724) IN CERTAIN REPRESENTATIVE SOILS OF THE UNITED STATES *

Description	Surface	Subsoil
8 residual soils, Robinson	1.76	.64
3 glacial and loessial soils, Robinson	4.59	1.44
2 Kansas till soils, Coll	2.86	1.98
6 Nebraska loess soils, Always	3.83	1.96
30 Minnesota till soils, Rost and Always	7.46	1.88

* From Lyon and Buckman, Nature and Properties of Soils (copyrighted). By permission of The Macmillan Co.

Snyder states that the average humus content of Minnesota surface soils is 3.66 per cent, and Hilgard found that in cultivated soils (not peats) of humid regions the humus content rarely exceeded 5 per cent and commonly fell below 3 per cent. In arid soils the humus was found frequently to fall below 0.3 per cent and rarely to exceed 1 per cent. Soils in the South have been found to vary in organic-matter content from similar soils further north. Loess from southern Illinois was found to contain 1.11 per cent organic matter, while loess from northern Illinois contained 3.86 per cent.[214]

Cameron found the same soil type to vary widely in organic matter in different samples: Norfolk fine sandy loam, from 0.3 per cent to 3 per cent; Porters sandy loam, from 1 per cent to 7.7 per cent; Orange-burg clay, from 0.6 per cent to 3.4 per cent; Hagerstown clay, from 0.7 to 3.7 per cent and Hagerstown loam, from 0.5 per cent to 3.1 per cent. The organic matter ultimately forms humus in the stricter sense, but the quantity of humus formed per unit of organic matter is not known. Hilgard has estimated that five or six parts of dry plant debris may form one part of humus, but considers it probable that the proportion is higher.

Composition of Organic Matter.—When vegetable matter is first turned under, the composition is that of the plants. Under suitable conditions of temperature and moisture, decay at once sets in and the microörganisms in the soil make changes in the composition of the organic matter. Carbon and nitrogen are used for food by the organisms, and the carbohydrate and protein molecules are broken down, part of the nitrogen of the latter being eventually transformed to nitrates. In this process not only are certain substances, such as carbon dioxide, given off, but a number of new organic compounds are formed, as well as organic compounds of phosphoric acid and potash. The resulting humus is a very complex substance and knowledge of its chemical constitution is still very incomplete. According to Jodidi,[137] "While the amount and nature of the humus formed in the soil primarily depends upon the quantity and character of the organic materials which undergo humification, it should be borne in mind that also other factors, like temperature, moisture, aeration of the soil, presence of certain chemical substances, (salts, acids, etc.), as well as character and quantity of microbes contained in the soil, have more or less influence upon the nature of humus produced."

The influence of the original organic matter on the composition of humus was shown by Snyder,[271] who mixed various substances with soil and later determined the composition of the humus formed. The results from three of these substances are given in Table V.

TABLE V *
COMPOSITION OF HUMUS PRODUCED BY:

	Cow Manure	Green Clover	Oat Straw
Carbon	41.95	54.22	54.30
Hydrogen	6.25	3.40	2.48
Nitrogen	6.16	8.24	2.50
Oxygen	45.63	34.14	40.72
Total	100.00	100.00	100.00

The older writers recognized ulmin and ulmic acid, humin and humic acid as constituents of humus; the first two being formed under anaerobic the last under aerobic conditions. Much work has been done on the problem of what these substances are, but as yet they are not well understood. A detailed discussion of the results of this work would be out of place in this book. It is sufficient here to say that humus is a very complex substance, but that, so far as the interest of the farmer is concerned, the important constituents are carbon and nitrogen. Under certain conditions there may be developed, however, toxic organic substances, the intermediate products of bacterial action. The presence of some of these, even in small quantities, has been shown to interfere with the growth of plants. In the course of decay, the carbon is lost more rapidly than the nitrogen, thus leaving old humus relatively richer in the latter element.

In soils long cultivated without the addition of organic matter, the nitrogen may be depleted more than the carbon, as shown by the following analyses by Snyder.[271]

TABLE VI *

COMPOSITION OF HUMUS IN NEW AND IN OLD SOIL

	Humus from New Soil, Per Cent	Humus from Old Soil, Per Cent
Carbon	44.12	50.10
Hydrogen	6.00	4.80
Oxygen	35.16	33.70
Nitrogen	8.12	6.50
Ash	6.60	4.90
Total humus material	5.30	3.38

* By permission of The Macmillan Co. (copyrighted).

In general, the humus of humid soils is said to contain from 3 to 12 per cent nitrogen, while the humus of arid soils is much richer in nitrogen, sometimes containing, according to Hilgard, as much as 14 per cent nitrogen. Recent work, especially by Waksman, appears to indicate that these figures are too high and that the nitrogen in humus rarely, if ever, is in greater amounts than 3 to 3.5 per cent. Phosphoric acid and potash are also combined with humus. According to Snyder:[268]

"In the case of rich prairie soils, over 500 pounds of phosphoric acid and 1000 pounds of potash per acre to the depth of 1 foot have been found to be in combination with the humus. In the case of soils poor in humus and worn by cropping, the amount may be reduced to 100 pounds per acre. The average of analyses of the mineral matter of the humus from samples of productive prairie soils yielding 25 per cent of humates showed 7.50 per cent of potash and 12.37 per cent of phosphoric acid. In these soils, which were well supplied with humus, 1500 pounds of phosphoric acid per acre out of a total of 8750 was combined with humus, and 1000 pounds of potash out of a total of 12,250 pounds. According to Hilgard, the amount of phosphoric acid usually found associated with humus varies from 0.1 to 0.5 of the total amount in the soil, indicating, in many cases, the amount of this element available to plants." [1]

Loss by Cultivation.—Organic matter is lost from the soil chiefly through cultivation. This loss is largely the result of the action of microörganisms, which are stimulated to greater activity by the increased

[1] This view has been questioned by Gortner and Shaw.

aeration and improved physical condition of the soil. In a soil wholly devoid of microorganic life, if such a one can be conceived to exist, plant material turned under would remain as it is; no decay would take place and no loss would follow. In uncultivated land, especially in that under sod, the amount of organic matter increases; in fact, such accumulations through the ages have been the chief source of the organic matter in virgin soils. Thatcher found that the humus and nitrogen in soils at Pullman, Washington, had been lost by cultivation, as has been shown in Table I.

Snyder [268] found in Minnesota that, after twenty years of grain cropping, the humus in the soil had declined from 4 per cent to 2.5 per cent. This loss of humus is the direct result of cultivation without proper attention to rotations or to returning organic matter to the soil. The effect of the soil treatment on the loss of humus has been brought out by Snyder,[208] who found 3.32 per cent of humus in a soil cultivated thirty-five years, but to which manures had been applied and on which a good rotation had been followed. Another soil, originally of the same kind, but which had been continuously cropped to grain for thirty-five years, contained but 1.8 per cent of humus. Humus may, of course, also be lost by oxidation processes other than those caused by microörganisms. Sievers and Holtz [261] found, in Washington, "that, after a period of thirty-nine years of farming, during which time only 20 crops were grown, 34.5 per cent of the organic matter and 22.1 per cent of the nitrogen have been lost from the soil." After forty-one years of cropping, the soil of the permanent fertilizer plots at the Pennsylvania Agricultural Experiment Station contained an average of 16,299 pounds of organic matter per acre less than the soil of the grass strips between the plots. It is clear that, unless care is exercised to prevent it, cropping and cultivation of the soil results in the loss of organic matter.

Measuring the Loss of Organic Matter.—The evolution of carbon dioxide has been used as a means of measuring the loss of organic matter. Organic matter is composed largely of carbon, and in decay a part of this combines with the oxygen in the soil air and forms carbon dioxide. Some of this is used as a source of energy by microörganisms, but the part that escapes into the air and can be weighed or measured represents so much loss of carbon and hence of organic matter. Many workers have, therefore, used the carbon dioxide evolved as a measure of organic matter lost. Among others, Potter and Snyder,[233] working with a Miami silt-loam soil, found that in fifty-three days, from July 10 to September 2, 1915, 797 pounds of organic carbon were lost per acre, while in soils variously treated, the losses were even larger.

Wollny [348] used this method extensively and, in an experiment on the effect of earthworms in facilitating decay, found the figures given in the table below:

TABLE VII

LOSS OF CARBON FROM SOILS WITH AND WITHOUT EARTHWORMS

(In Volumes of Carbon Dioxide per 1000 Vol. of Soil Air)

	With Earthworms	Without Earthworms	With Earthworms	Without Earthworms
From Nov. 7-16:				
Average of 8 experiments	5.43	3.88	8.04	3.08
From Nov. 19-28:				
Average of 9 experiments	3.07	2.52	5.61	1.90

This shows that loss of carbon as carbon dioxide went on more actively in soils with earthworms than in those without them. Besides losses that may be detected by measuring the carbon dioxide that passes into the air, carbon is lost by drainage as bicarbonates or to some extent as carbonates. Lyon and Buckman give the following data:

TABLE VIII *

LOSS OF CARBON FROM SOIL IN DRAINAGE

(Expressed in Pounds per Acre per Year. Cornell Lysimeters)

Treatment	Carbon Lost
Bare soil	273
Rotation	265
Grass	235

* From Lyon and Buckman. The Nature and Properties of Soils (copyrighted). By permission of The Macmillan Co.

The loss here was somewhat less under grass than in bare or cultivated soil.

Loss of Organic Matter Caused by the Use of Lime.—Any substance that stimulates the growth of microörganisms must cause an increased evolution of carbon dioxide and ammonia, and hence it is evident that a loss of organic matter may be expected from the application of lime and fertilizers as well as from aeration due to cultivation. Most soil microörganisms are stimulated in their growth by lime, and many need a good supply of phosphates as well. When soil conditions are favorable, that is, when there is an abundance of carbohydrate and nitrogenous material, together with lime and phosphates, and under appropriate conditions of moisture and temperature, microörganisms may increase to enormous numbers. Such increase carries with it an increased consumption of carbon for energy with the evolution of carbon dioxide, a breaking down of the protein molecule with the production of ammonia, and the subsequent formation of nitrates. The latter may be leached out of the soil or, under certain conditions, nitrogen may be set free as gas. By all these processes material is lost and the organic matter content reduced.

A loss of carbon must mean a loss of organic matter and, hence, the quantity of carbon dioxide found in the soil air under various conditions has been used as a measure of such loss or of decomposition. Unfortunately, the conclusions drawn from experimental work on the effect of lime on the loss of organic matter are by no means in harmony. Wollny [348] concluded that lime did not hasten the decomposition of fresh organic matter (straw), but did hasten decay of organic matter already partially decayed (peat). On the other hand, Lemmermann and associates, also using the evolution of carbon dioxide as a measure of decay, concluded that both caustic lime and carbonate of lime increased the rate of decay of such material as fresh rye leaves, vetch hay, lucerne and lupines, and that the loss of carbon was in proportion to the amount of calcium oxide used. The effect of calcium carbonate on the decomposition of lupine leaves, as given by Lemmermann and associates, is as follows:

	Loss of Total Carbon, in Per Cent
Soil check	1.24
Soil + green manure	11.14
Soil + lime	15.36
Soil + green manure + lime	21.07

More recently, Potter and Snyder [233] have investigated this subject in a careful study and have shown that the addition of 3 tons of calcium carbonate per acre resulted in an increased loss of carbon. Account was taken of the inorganic carbon lost, the difference between total carbon lost and inorganic carbon lost, representing the loss of organic carbon. As will be noted in Table IX, prepared from data in Potter and Snyder, Table III, the addition of calcium carbonate caused an increased loss of organic carbon in every case.

TABLE IX
LOSS OF ORGANIC CARBON BY VARIOUS TREATMENTS
(All Figures in Pounds per Acre. After Potter and Snyder)

Soil Treatment	Organic Carbon Lost
None	729
3 tons $CaCO_3$	931
10 tons manure	1115
10 tons manure + 3 tons $CaCO_3$	1216
1 ton oats	1219
1 ton oats + 3 tons $CaCO_3$	1388
1 ton oats + 10 tons manure	1555
1 ton oats + 10 tons manure + 3 tens $CaCO_3$	1741
1 ton clover	1342
1 ton clover + 3 tons $CaCO_3$	1490
1 ton clover + 10 tons manure	1629
1 ton clover + 10 tons manure + 3 tons $CaCO_3$.	1826

Hopkins [123] has claimed, on the basis of Hess' work on the Pennsylvania Fertilizer plots, that caustic lime destroyed organic matter, while ground limestone did not, but White and Holben[331] have shown that Hess' work is faulty because of a previously unknown deposit of fine charcoal on some plots. However, in another paper,[332] these authors, reporting on the loss of organic matter in limed and unlimed manured plots, say "Manure has decomposed at an average annual rate of 5428 pounds per acre where lime was applied, compared to 5071 pounds when used alone." The Rhode Island Station has shown, as calculated by Mooers and associates, a loss of .35 per cent in soil humus in two years by the addition of 4 tons air-slaked lime per acre, and these workers found in Tennessee that, in a five-year rotation of wheat and cowpeas, there was no increase of humus on the section treated with burnt lime, even where the cow-peas were turned under, while there was a loss of 3.17 per cent on those plots from which the cowpeas had been removed.

Brown [30, 31] found, in both laboratory and field studies, that the application of ground limestone stimulated bacterial activity, as evidenced by the increased number per gram after liming. This resulted in an increased production of ammonia and of nitrates, and since these were produced from the organic matter, an increased production of ammonia and nitrates must mean an increased consumption of organic matter. Fulmer [78] also found that calcium and magnesium carbonate increase the numbers of bacteria. Other workers in France, in Germany, and in America have come to similar conclusions.

It may be said, then, in general, that lime causes **a** decrease in the organic matter of soils and that such decrease is due to the increased bacterial activity caused by lime. In large part, however, such decrease is merely the necessary accompaniment of the soil organic matter being made available to higher plants.

Effect of Minerals other than Lime.—The effect of minerals other than lime has not been so extensively studied. It has been shown that microörganisms require the same elements as those used by crop plants and that they are favorably affected by the presence of potassium and of phosphorus, especially the latter. Fred and Hart found that soluble phosphates greatly increased the numbers of bacteria so that in some cases these numbers ran as high as nearly 4,000,000 per cubic centimeter and that the decomposition of organic matter was stimulated. The addition of potassium and of calcium phosphate caused an increase in the evolution of carbon dioxide.

Wollny[348] found that, when the minerals were removed from a humus-rich field soil by boiling with hydrochloric acid, the production of carbon dioxide was much reduced. In another experiment, rye straw was moistened with a solution containing various minerals, and upon decay more carbon dioxide was evolved from samples thus treated than from those moistened with water.

Whatever increases the activity of microörganisms increases their consumption of soil organic matter, whether fresh or old; and, while-part of this is merely changed in form, the amount given off as carbon dioxide or as ammonia, when this escapes into the air, represents organic matter lost.

Gain in Organic Matter from Green Manuring.—It is to be expected that green manuring will increase the organic matter in soils. Potter and Snyder [233] give the amount of carbon in 1 ton of dry matter of ripening oats as 861 pounds, and in 1 ton of dry matter of clover as 898 pounds. In general, when green crops are turned under, about 1 ton in 5 may be taken as dry matter, much of which consists of carbon. A large part of this carbon is immediately lost as carbon dioxide during decay, and other losses naturally occur as the organic matter is broken down and made available to crops. A residue, however, remains, the amount depending on conditions. Potter and Snyder found that, out of 861 pounds of carbon added to soils as dried oats, 318 pounds were lost, and that out of 898 added as clover, 545 pounds were lost, in each case by the evolution of carbon dioxide alone. The amount of organic matter lost by production of ammonia is not given, but a part was certainly lost that way; the remainder was added to the soil humus.

Sievers and Holtz [261] found that, when wheat straw containing 39.25 per cent carbon was decayed in soil, the loss of carbon as carbon dioxide accounted for 86 per cent of the straw applied. Vetch lost carbon as carbon dioxide equal to 41 per cent of the vetch applied, indicating, "that when a crop residue containing a high per cent of nitrogen is applied, the kind of decomposition that takes place does not go through to completion, but apparently results in the accumulation of humified organic matter in the soil." While it is not possible to say how much of the carbon in green manure turned under remains eventually to enrich the soil in organic matter, there is no question that such enrichment commonly takes place. Mooers and associates found that, when cowpeas were turned under without lime, there was in five years a gain of 3.79 per cent in soil humus, and that where the cowpeas were removed, there was, on the unlimed section, a gain of 2.32 per cent, this gain coming from roots and stubble, leaving a gain of 1.47 per cent, due to the incorporation of the cowpea tops. In this connection, it must be borne in mind that the tops decay more rapidly than roots and stubble, hence the relatively greater gain in humus from the latter. In a later publication, however, Mooers has shown that after twenty years of turning under cowpeas, the soil contained less humus in both limed and unlimed sections than at the beginning of the trials.

After five years of the turning under of rye and legume green manures on the rotation plats, Hartwell found that the loss by ignition on the check plat was 4.37 per cent; on the rye plat, 4.54 per cent; and on the legume plat, 5.07 per cent, indicating a gain in organic matter as a result of green manuring. At the Pennsylvania Station, White [329] found that all the green manures used left the soil richer in organic matter nine months after their addition. The gain was greatest with clover; rye, timothy, red top, and alfalfa followed in that order. In California, however, Madson reported no gain in humus from the turning under of green-manure crops, all the organic matter having been oxidized in one season.

Frear and Hess studied the changes in organic-matter content for a number of plats treated with manure and with artificial fertilizers. The plats that received in the course of twenty years a total of 12 tons of organic matter per acre in stable manure, contained at the end of that period 4 tons of organic matter per acre more than the check plats, while the plats treated with artificial fertilizers showed a gain of about 1½ tons. The gain in organic matter on these plats was derived from the larger quantities of roots and plant residues which remained on the fertilized plats as compared with the check plats.

White and Holben [332] also call attention to the fact that, in spite of the greater consumption caused by liming, the increased amounts of roots and other crop residues on the limed and manured plots had resulted in a gain in total organic matter. It was estimated that 93 per cent of this gain was due to crop residues.

Schreiner [250] found that the turning under of green-manure crops in an unproductive pecan-orchard soil increased the content of organic matter from 1.11 per cent in 1918 to 1.56 per cent in 1921, 2.13 per cent in 1922 and 2.4 per cent in 1923, the organic matter content of this soil being more than doubled in five years.

While there is unfortunately a dearth of exact data on this subject, the fact that turning under green crops increases the organic matter of the soil is abundantly attested by practical observation. The darker color of light soils and the improved tilth of heavy soils give evidence of an increase in the humus supply of soils to which green manures have been added.

Role of Organic Matter in Soil.—The role of organic matter has long been recognized to be that of a maintainer of soil productivity. Agee considers that for most farming land the amount of organic matter largely determines the productive power of the soil. This is equally true for the lands in humid sections and for those in semi-arid sections although the importance of organic matter in the latter was not so early recognized. That it is of great importance even in dry-farming sections is admitted by many workers. Thatcher says: "Recent researches, however, have shown that the humus of the soil is so influential a factor in its water-holding capacity and successful tillage that it is now known that the humus content of the soil is fully as important in dry-farming regions and practices as in the older types." That the crop-producing capacity of soils is closely related to the humus content of these soils was brought out by Cates, who gives the following data:

TABLE X

RELATION BETWEEN HUMUS CONTENT AND CORN YIELD

Per Cent Corn Yield
Soil State ,
of Humus per Acre

Cecil clay	North Carolina	1.5	20
Hagerstown loam	Virginia	2.25	30
Miami clay	Ohio	5.0	45-50
Illinois prairie	Illinois	5.0	45-50
Houston clay	Texas	3.75	30-35
Marshall silt loam	Nebraska	3.5	35
Carrington silt loam	Iowa	3.0	35-40

While it is true that plants may be grown to maturity in quartz sand, to which the necessary elements have been added and which is totally devoid of organic matter, such experimental results can be secured only under conditions of moisture and temperature control and when the cost of production is not considered. Field crops grow under quite different conditions and the presence of organic matter is generally essential to successful and economical crop production.

The functions performed by organic matter may be considered as of two general kinds, physical and biochemical.

Physical Effects.—Organic matter affects both the texture and the moisture-holding capacity of a soil. Texture of a soil influences tilth, which has long been known to be of primary importance for the good growth of crops. The quality of crumbliness, which a clay exhibits when it readily separates into small granules, is imparted to it by organic matter, Figs. 4 and 5.

Mosier showed that, when the organic matter was removed from a clay soil, this remained hard upon being wetted and frozen, whereas when the same organic matter was returned to the soil, it became friable when frozen. This influence of organic matter in improving the tilth of the soil has been repeatedly observed and reported by agricultural workers. On the Barnfield field at Rothamsted, on which mangolds received only artificial fertilizers, the soil is reported to have gotten into such bad physical condition, "sticky and unworkable," that, "under bad weather conditions, the young plants grow only with difficulty, whereas on the plots receiving dung annually the soil is always in good heart." [225] Of the wheat field, the same author says: "In the classical wheat experiments (Broadbalk field) the dunged plot can always be relied upon to give a good crop of wheat, withstanding adverse conditions well, and fluctuating much less from year to year than the crops on adjoining plots, which receive only artificial manure."

FIG. 4.—Vertical section through soil near a maize plant on newly broken alfalfa sod. Note the crumbly appearance of the soil due to an abundance of organic matter. (U. S. Department of Agriculture.)

Drinkard, in Virginia, reports the physical condition of soil greatly improved by turning under green manures. When heavy soils are constantly cultivated, they lose organic matter and tend to puddle. This condition has been especially noticeable and harmful on many irrigated lands in the arid regions, and workers in California, Oregon, and Washington have commented on the beneficial effects of green manuring in correcting the tendency of the soil to puddle. In sandy soil, on the other hand, organic matter tends to bind the particles together and thus to decrease the tendency of such soils to blow. This has also been found true of some peat soils which, with constant cultivation, tend to become so fine as to be unworkable and to blow away much like fine sand. Turning under a crop of soybeans for green manure corrects this trouble.

Aëration.—The presence of organic matter improves the aëration of clay soils by making them more open. Organic matter does not pack as tight as clay, and the volume weight of humus is very much less than that of mineral soils. Hilgard, quoting Wollny, gives the volume weight of humus as .3349; clay, 1.0108; and sand, 1.3385. Dyer has shown that a plot of soil heavily manured for fifty years decreased in weight of the surface 9 inches from 2,478,780 pounds per acre to 2,333,891 pounds as a result of he accumulation of organic matter. The improvement of aeration is, of course, most beneficial in clays.

FIG. 5.—Vertical section through soil depleted of organic matter by continuous maize culture. Note the stiffness of the soil; a poor place for roots.
(U. S. Department of Agriculture.)

Moisture.—Organic matter is very retentive of moisture; and the addition of decomposed and decomposing organic matter to sand greatly increases the water-holding capacity of the mixture. Mosier gives the following data:

TABLE XI '
EFFECT OF ORGANIC MATTER ON RETENTION OF MOISTURE

	Grams of Water Retained by 100 Grams of the Mixture
Coarse sand	13.3
Coarse sand + 5 per cent peat	18.6
Coarse sand + 10 per cent peat	24.7
Coarse sand + 20 per cent peat	40.00
Peat	184.00

Ulrich found that the water-holding capacity of mineral soils decreased with increasing temperature; the contrary was the case with humus. With the water capacity at 0° C. placed at 100, a humus-rich sand showed a water-holding capacity of 102.67 at 20° C, and of 104.64 at 30° C. Peat showed a water-holding capacity, at 30° C, of 529.83, 770, and 1065.96 in each of three samples studied.

Alway and Neller, however, did not find a material difference during a dry year between the moisture content of a soil that had been continuously in corn and contained 3.39 per cent organic matter and one on which clover had been used in the rotation and which contained 4.76 per cent, organic matter. The soil with which these investigators worked was, however, a very good soil. On the other hand, Stewart,[276] discussing the effect of organic matter on soil fertility, shows that in a dry year the

Rothamsted plats receiving stable manure outyielded those receiving artificial fertilizers, though in years of average rainfall the relation as to yields was reversed. Stewart says, "The fifty-five year average yield of wheat from Plot 2, (Broadbalk field), receiving farm manure, is 35.5 bushels; while that of Plot 8, receiving minerals and nitrogen, is 37.1 bushels. In the year 1893, however, which was an extremely dry year, the yield of wheat from Plot 2 was 34.3 bushels, while the yield from Plot 8 was only 21.8 bushels." The experience of farmers on light soil is decidedly to the effect that the turning under of organic matter helps to carry crops through a dry spell.

Temperature.—Owing to its dark color, humus absorbs heat more readily than mineral soils. On the other hand, the high water capacity of soils rich in humus tends to retard the rise of temperature in such soils and, under conditions of rapid evaporation, even to cool them. A peaty soil, when wet, is slower to warm up in spring than a sandy one, but is also the last to freeze in winter. However, while this is true of a peat which holds an excessive amount of moisture, a good arable soil rich enough in organic matter to be dark colored warms up more quickly in spring than does a light-colored soil. Mosier gives the following data from an experiment in which a part of a field was covered with a thin layer of black loam and the soil temperature taken at hourly intervals between 11 a.m. and 5 p.m.

TABLE XII

EFFECT OF COLOR OF SOIL ON TEMPERATURE

TIME	LIGHT 1 Inch Below Surface Degrees F.	DARK 1 Inch Below Surface Degrees F.	LIGHT 2 Inches Below Surface Degrees F.	DARK 2 Inches Below Surface Degrees F.	LIGHT 4 Inches Below Surface Degrees F.	DARK 4 Inches Below Surface Degrees F.
11 A.M	78	82	74	75	69	70.5
12 M	81	86.5	77.5	81	73	75.5
1 P.M	83	91	80	86	76.5	81
2 P.M	85	92	81.5	88	78.5	84
3 P.M	86	91	82	88	80	86
4 P.M	85	89	82	88	81	87
5 P.M	81.5	85	81	86	81	86

While the decomposition of organic matter in common with all oxidation processes is accompanied by a rise of temperature, this is so small as to have no effect on the temperature of the soil. Wollny,[348] quoting F. Wagner, says that it would require 50,000 kilos per hectare (nearly 45,000 pounds per acre) of horse or sheep manure or legume straw, under favorable conditions of decomposition to raise the soil temperature 0.1 to 0.4° C.

Biochemical Effects.—The organic matter of soils has been said to be a storehouse of nitrogen. This is perhaps its more important function, but since plants are unable to use the combined organic nitrogen as turned into the soil, this must first be broken down by the action of soil microörganisms. All arable soils support an abundant life, animal and vegetable, macroscopic and microscopic, but the transformation of organic compounds into material for plant food is largely effected by the microscopic organisms. As already stated, worms and insects do help in breaking down organic matter, but even after this has passed through their digestive tracts, it must still be further broken down by bacteria and fungi before plants can use it.

The entire range of recent studies on the biological activities in soils depends on the presence of organic matter. The various means suggested to determine the fertility of soils by biological methods revolve about the fact that microörganisms attack organic matter and that, as a result of the activities of these organisms, certain end products, useful to crop plants, are produced.

Soil Organisms Break Down Organic Matter.—The microörganisms that are prominent in the breaking down of organic matter are of three classes: fungi, bacteria and protozoa, all of which are present in enormous numbers and are represented by many species. Some of these species do similar work in the soil, others are highly specialized, and can thrive only under certain conditions, attack certain substances and leave certain definite products.

As the complex carbohydrate and protein molecules of organic matter are broken down, the secondary products are in turn attacked by other organisms, which break them down further. The parts of the plant-remains most readily broken down are first attacked, until finally substances remain that are more resistant, and these form the humus of soils. These more resistant compounds, too, are more or less slowly broken down and, if conditions remain favorable, the end products will be the elements of which the plant material was composed—largely carbon, oxygen, hydrogen, and nitrogen, all escaping into the air in one form or another. Lipman [172] calls the bacteria in the soil, the great scavengers intrusted with restoring to circulation the various elements held fast in the dead bodies of plants and animals.

Classes of **Soil Microörganisms.**—In this book, only a very brief and general account can be given of these organisms. For further information the reader is referred to standard texts on the subject.[1]

Bacteria: Bacteria are single-celled organisms which reproduce by division. Under favorable conditions large numbers may be produced in a short time. In shape they are rod-like, spherical or corkscrew shaped and are motile or non-motile, Figs. 6 and 7. In the decomposition of organic matter three groups are of chief importance; cellulose decomposing, ammonifying, and nitrifying organisms.

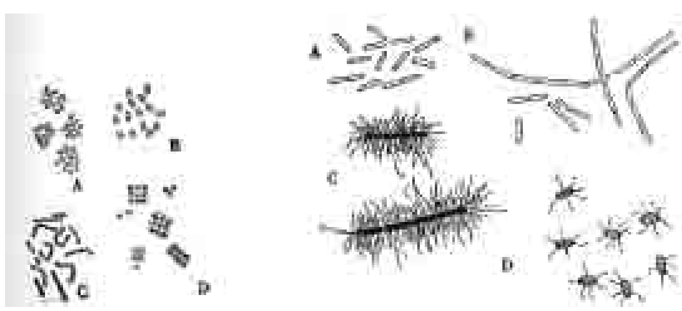

FIG. 6.—Bacteria: at left, Coccus forms; at right, Bacillus forms.
Coccus forms of bacteria: *A, Slaphylococcus; B, Diplococcus; C, Streptococcus; D, Sarcina.* All magnified about 1000 X. Bacillus forms of bacteria. *A, Bacillus sporogenes; B, Bacillus subtili3; C, Bacillus proteus; D, Bacillus typhosus.* All magnified about 750 X. (From Holman and Robbins, Text Book of General Botany, John Wiley & Sons, Inc., New York 1924.)

[1] See Conn, H. W. Agricultural Bacteriology. 1901. Lipman, J. G. Bacteria in Relation to Country Life. 1911. Russell, E. J. Soil Conditions and Plant Growth. 1915. Russell, E. J., and others. The Micro-organisms of the Soil. 1923. Lohnis, F., and E. B. Fred. Textbook of Agricultural Bacteriology. 1923. Lohnis, F. Handbuch der landwirtschaftlichen Bakteriologie. 1910.

Fungi: Fungi are organisms of higher organization than bacteria and, while often minute, may attain considerable size. The body or mycelium consists of many interwoven branched threads called *hyphæ,* and these may be divided by cross walls into a number of cells or may be undivided. Fungi reproduce by spores which are often produced in great numbers. The common green mold is a typical fungus, Fig. 8. Among fungi species of Actinomyces found in soils have been considered by some to be related to bacteria and have been so classified. Drechsler has shown, however, that these minute organisms are typical fungi, but that the organism so readily breaks up into minute rod-shaped fragments that many workers have mistaken them for bacteria. Fungi decompose cellulose and produce ammonia from protein substances.

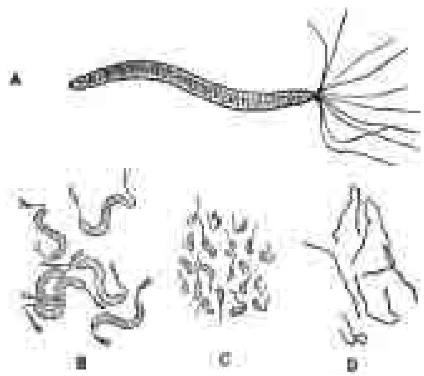

FIG. 7.—Spirillum forms of Bacteria.
A, A species of *Thiospirillum* (a sulphur-oxidizing organism); *B, Spirillum undulum; C, Vibrio cholera; D,* a species of Spirochæte. All magnified about 1000 X. (From Holman and Robbins, Text Book of General Botany, John Wiley & Sons, Inc., New York. 1924.)

Protozoa: These are minute single-celled animal forms the presence of which in soils depends primarily on moisture. They are commonly found in smaller numbers than bacteria, but Hiltner reports having found millions of Amoebae and Flagellates in 1 gram of earth. At Rothamsted 1,500,000 amoebae have been found in 1 gram of soil. It seems improbable that these organisms play any very large part in the breaking down of organic matter, but information regarding their life histories and the part they play in the soil is scanty. Löhnis [180] states that some species can take part in the decomposition of moist plant remains and change organic nitrogen into ammonia.

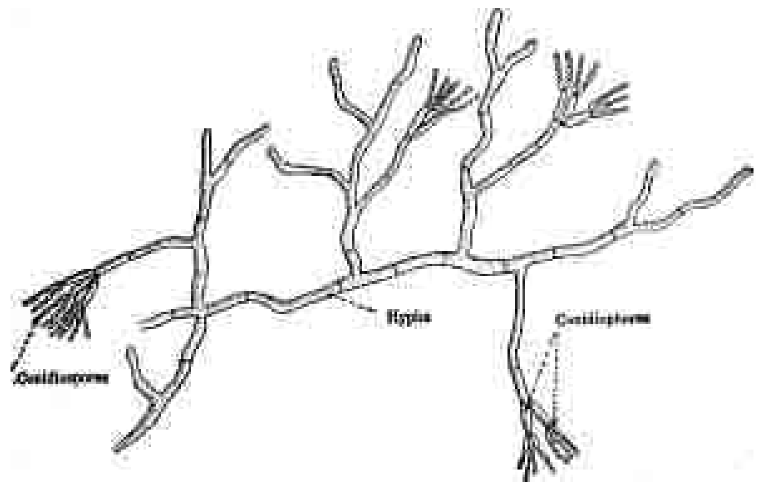

FIG. 8.—A typical soil fungus, Penicillium Sp.
(From Holman and Robbing, Text Book of General Botany, John Wiley & Sons, Inc., New York, 1924.)

Russell and Hutchinson were the first to call attention to the part these minute animal forms belonging mainly to the groups *Amoebae, Flagellates,* and *Ciliates* may play as destroyers of bacteria in the soil. These authors concluded that, where protozoa are active, they may reduce the numbers of bacteria and thus exert a harmful effect on soil fertility. Waksman [308, 311] and Waksman and Starkey,[319] however, doubt the correctness of this conclusion. Waksman points out that while *Flagellates* are active in normal soil, the *Ciliates* require more moisture and in his cultures, were active only when the soil moisture rose to 28 and 42 per cent. He found no relation between the production of ammonia and the presence of protozoa, and says: "The results brought out in this paper show that, though protozoa may be detrimental to bacterial members, they do not influence the ammonia accumulated in the soil, a fact which is the important part of the question, and with which we concern ourselves in studying the problems of soil fertility." Novikoff also considers that the importance of soil protozoa has been overrated. The subject is still new, and, while a considerable literature has already appeared, the technique is difficult and more studies are needed before a final conclusion can be reached.[1]

Alga: Numerous forms of microscopic green algæ have their home on or just under the surface of the soil, especially a wet soil, but so far as known they are of no agricultural importance.

Ammonifying Organisms.—Besides carbon dioxide, which is given off in decay, one of the products of decay is ammonia, produced through the breaking down of protein substances by a number of bacteria as well as by fungi. This process is known as ammonification and the bacteria concerned are collectively called ammonifying bacteria. The ability of all the organisms in a given soil to break down protein into ammonia is called the ammonifying power of the soil. Some of the most active ammonifiers among the bacteria are *Bacillus mycoides, B. vulgaris,* and *B. sublilis.* Others are also active and in general bacteria attack proteins more readily than the carbohydrates, except the simpler ones, while fungi attack both proteins and carbohydrates. Although more work has been done on ammonification by bacteria, it is probable that fungi play at least as

[1] The student is referred to Kopeloff and Coleman for an excellent review of the literature.

important a part. Waksman [312] has isolated more than 200 species of fungi from soils and many of these belonging to the genera *Penicillium, Aspergillus, Citromyces, Mucor, Rhizopus, Monilia, Trichoderma,* and others, are active ammonifiers. Species of *Trichoderma* are said to be the most efficient, while actinomycetes are not efficient ammonifiers. Russell [242] states that some ammonia may be produced even when the action of microörganisms is inhibited by antiseptics, but certainly by far the greater part of the ammonia produced, if not nearly all, is the result of the activity of living organisms.

Nitrite and Nitrate Bacteria.—These differ strikingly from the ammonifying bacteria in that their action is confined to certain substances and that the number of species involved is very limited. Winogradski, who first worked out the life history of these forms, found but two genera, one in the Old World, which he called Nitrosomonas, and one in the New World, which he called Nitrosococcus, involved in the transformation of ammonia into nitrites; other investigators, however, believe these to be but two forms of the same organism. Winogradski also found but one organism, Nitrobacter, able to transform nitrites into nitrates. Nitrosomonas (or coccus) occurs as small oval motile rods, or in a globular form, while nitrobacter is a non-motile rod. In good soils, these ammonifying, nitrite, and nitrate-producing organisms are all present and their action is so well correlated that the ammonia is rapidly transformed into nitrites and these into nitrates, in which form the nitrogen is most readily used by crop plants. The ability of the organisms of a given soil to produce nitrates is called the nitrifying power of the soil.

Cellulose Decomposing Organisms.—Since cellulose is, next to lignin, the most resistant of the carbon compounds turned into the soil by green manuring, the organisms taking part in the breaking down of cellulose are of especial interest. Unfortunately, there is little definite information in regard to the organisms themselves or in regard to the chemistry of cellulose decomposition. Both aerobic and anaerobic bacteria, as well as fungi, are believed to take part in this work. Several bacteria are known to be involved and one is said to be so specialized that it can live only on cellulose. Under proper conditions, as when straw decays in the presence of plenty of available nitrogen, the numbers of these bacteria may become very large.

McBeth isolated 36 species of cellulose destroying bacteria. Waksman and Heukelekian state that fungi decompose cellulose in the ratio of about 30 parts cellulose to one of nitrogen used, while bacteria require smaller amounts of nitrogen, decomposing cellulose in the ratio of 45 to 54 parts to one of nitrogen. In slightly acid soils, fungi are most active, while in neutral or alkaline soils both fungi and bacteria are active. Waksman [313] mentions, as powerful cellulose decomposers, species of *Trichoderma, Cephalosporium, Aspergillus, Penicillium, Verlicillaria,* and others.

Species of Actinomyces are widely distributed and are powerful cellulose decomposers; Waksman and Curtis describe 30 species or groups. At a depth of 1 inch they were found to constitute 7.3 to 12.1 per cent of the total soil flora, while at a depth of 30 inches, their relative numbers had increased to 52.7 or 83.6 per cent of the total.

Soil Microörganisms Consume Nitrogen.—All forms of life require nitrogen for the building of protoplasm and microörganisms, except the nitrogen fixers, are no more able to use atmospheric nitrogen than crop plants. They must, therefore, consume the organic nitrogen in the soil, or the ammonia or nitrates formed from this organic nitrogen. When large quantities of carbohydrate materials low in nitrogen are present in soils, the bacteria and fungi breaking this down, use whatever nitrogen they find available and, under favorable conditions, may reduce the available nitrates in a soil and thus retard the growth of the crop. Arnd found that, on heavily limed peat soils, the nitrates were consumed by the microflora which had been stimulated by liming. Koch [157] found that the addition of cellulose in plant residues as a source of energy, increased the numbers of bacteria which converted available nitrates into albuminoid substances and thus decreased the growth of crops. Viljoen and Fred found that the presence of fine wood or of cotton cellulose in cultures caused a reduction of nitrates. Scott added wheat straw to greenhouse soil and noted a decrease in nitrate content proportional to the amount of straw applied, while Rahn found that the addition of easily assimilable carbon compounds caused an increase in the number of microörganisms and a fall in the nitrogen content of the soil. Waksman and Starkey [319] believe that fungi, especially actinomycetes, are more active in cellulose decomposition than bacteria, and point out that, because of their activity in attacking carbohydrates, fungi store large quantities of nitrogen in their bodies. When highly nitrogenous material is turned under, it will supply the needs of the microflora, as well as leave a surplus as ammonia to be later converted into nitrates. On the one hand, therefore, the microflora of the soil competes with the growing crop for nitrogen and in some cases may even damage the crop; on the other hand, when soluble nitrates are in excess the locking up of these in the bodies of bacteria or in fungus mycelium may be useful and prevent loss by leaching.

Denitrifying Organisms.—A number of organisms are known that can liberate nitrogen from nitrites in the process of using the oxygen, the nitrogen being liberated as gas. This process is known as denitrification. The nitrates are reduced to nitrites and from these the nitrogen is set free. It is believed that some bacteria may set free nitrogen directly from nitrates. Denitrification commonly takes place in soils when little or no free oxygen is present, and this means commonly waterlogged, poorly drained soils and the presence of considerable amounts of decaying organic matter from which the bacteria may procure carbon for energy, as well as available nitrates. In a well-aerated soil, without excessive amounts of organic matter, the loss of elemental nitrogen is insignificant or wanting. There appears to be evidence that some fungi can reduce nitrates to nitrites, but none that they carry the process further and set free gaseous nitrogen. A clear distinction must be made between denitrification and transformation of nitrates. In the former, the nitrates are finally reduced to gaseous nitrogen, which returns to the air and is lost. Nitrates may also be utilized by the microörganisms of the soil for the building up of their own protein. In this case, the nitrate is rendered unavailable to the growing crop, but the nitrogen is not lost, but transformed and may become available later. Some writers have included this kind of nitrogen transformation under denitrification.

Symbiotic and Non-symbiotic Nitrogen Fixers.—While most soil microörganisms are dependent upon organic nitrogen there are two great groups of soil bacteria known to fix atmospheric nitrogen. One group works in the roots of legumes and, since the relation is believed to be advantageous to both the legume and the microörganism, this relation is said to be symbiotic; the other group consists of free-living soil bacteria. While the nodules on the roots of legumes harbor bacteria, the roots of many shrubs and trees, are inhabited by fungi, which are believed to fix nitrogen; these, however, are not of agricultural importance.

Of the non-symbiotic soil bacteria able to fix nitrogen, the species of Azotobacter are important. Several species of this genus have been described, all of which can fix atmospheric nitrogen under aerobic conditions when lime and carbohydrates are available. Another organism, *Clostridium Pastorianum,* fixes atmospheric nitrogen under anaerobic conditions and has been found to be more effective when associated with other bacteria. Other soil organisms are also said to be able to fix atmospheric nitrogen, but most of the literature on this subject deals with forms of Azotobacter.

Numbers of Soil Organisms.—The number of microörganisms in soil varies so greatly with conditions that no definite figures can be given. Further, no one culture medium will develop all the organisms in a given soil. Anaerobic bacteria will not grow in the presence of free oxygen; an acid medium favors the development of fungi and suppresses the bacteria, while bacteria of the Azotobacter type do best in a medium free, or nearly free, from organic nitrogen. Workers have, therefore, developed various special culture media on which one or another type may be grown; the study of soil protozoa requires a special technique.

The figures given below are illustrative, therefore, rather than absolute and some of them show the effect of increased food supplies on the numbers of organisms. Numbers are given per gram or per cubic centimeter of soil.

Waksman [310] gives the following table, showing the numbers of bacteria and fungi found by various workers.

TABLE XIII

NUMBER OF BACTERIA AND FUNGI PER GRAM OR PER CUBIC CENTIMETER OF SOIL

	Bacteria	Fungi
Remy, per gram	1,770,000 to 2,500,000	200,000 to 240,000
Raman, per c.c.	2,400,000	129,000 to 289,000
Raman (raw humus), per c.c.	220,000	241,000
Fischer (Moorland), per gram	1,600,000	550,000
Fischer (Moorland) + manure	777,000	1,116,666
Fischer, sandy soil	1,450,000	733,333
Fischer, sandy soil + manure	3,650,000	1,816,666
Waksman, per gram	4,000,000 to 20,000,000	

In one experiment, Waksman found as many as 1,536,000,000 bacteria after seven days incubation at 14 per cent moisture.

The addition of readily available carbohydrates quickly results in a great increase in the numbers of organisms. Fred [70] added 2 per cent sugar to a soil and found the following increases in the bacterial numbers:

	After 8 Days	After 21 Days	After 41 Days
Control	9,100,000	14,800,000	17,400,000
2 per cent sugar	74,800,000	189,500,000	393,200,000

The addition of dextrose and mannite to a soil caused Azotobacter to increase to 350,000,000 per gram of soil [315] and, in one experiment,[76] the addition of soluble phosphates resulted in the development of bacteria to the enormous number of 3,941,000,000 per cubic centimeter.

McLean and Wilson found that the addition of acid phosphates up to one-half of 1 per cent to soil increased the number of bacteria per gram from 184,000,000 to 240,000,000 when one-half of 1 per cent acid phosphate was added. Further additions of acid phosphate caused a decrease in numbers to 12,200,000 when 5 per cent acid phosphate was added.

Waksman and Starkey [320] found that on the addition of straw the number of fungi per gram of soil increased in seventeen days from 87,300 to 320,000, while when nitrate was added to the straw the number in seventeen days was 3,100,000. It must be noted, however, that numbers given for soil fungi can not be taken too literally. The colonies plated out arise from spores and one fungus mycelium in a gram of soil may, at one stage, give rise to thousands of spores and, at another, to none at all. In the spore stage, the count will show the presence of many fungi, while at the other stage there may be no fungi in the culture. The increase above shown may mean only that the fungi present were stimulated to greater spore formation.

Number at Different Depths and at Different Seasons.—Waksman [309] found the greatest numbers of bacteria in April and May and at a depth of 1 to 4 inches. On April 16th, the numbers recorded were 10,700,000 at a depth of 1 inch; 21,400,000 at 4 inches; 1,690,000 at 12 inches and 606,000 at 30 inches. Fungi are said to be present in greatest numbers at depths of 1 to 4 inches.

Owing to the difficulties of technique, counts of protozoa are very uncertain, but Waksman [308] gives 2000 to 5000 flagellates at a depth of 1 to 8 inches and a moisture content of 9 to 9.4 per cent. At 12 inches and a moisture content of 8 per cent there were 10 to 100 flagellates. At higher moisture content, the number of flagellates increased. At a depth of 1 inch and 17.3 per cent, moisture, there were found 5000 to 10,000 flagellates. At a depth of 12 inches, however, and a moisture content of 11.3 per cent, the number remained 10 to 100.

SUMMARY

The source of the organic matter in soils has been shown to be the plant and animal residues, especially plant roots, gradually incorporated with the soil through the ages. The amount of organic matter in soils varies widely and is of two kinds,—humus, and less completely decomposed plant and animal remains. The total organic matter may be nearly two or more times that of the humus, and may vary in different soils from less than one to more than five per cent. The different methods that have been employed to determine the humus or organic matter content of soils may give results varying 100 per cent or more for the same soil.

As organic matter decomposes in the soil the complex molecules are broken down, the carbon and nitrogen are in part used by microörganisms and in part escape as gas or are transformed to other substances. The humus resulting from decay is a complex and little understood substance. The carbon of organic matter disappears relatively faster than the nitrogen, but in soils long cultivated the nitrogen may disappear more rapidly than the carbon. It seems probable that the nitrogen in humus does not often exceed 3 to 3.5 per cent.

Organic matter is lost through cultivation and this loss is eventually reflected in decreased crop yields. The loss of the carbon in organic matter can be measured, at least approximately, by determining the carbon dioxide evolved, and such loss, being due to oxidation resulting from the activities of soil microörganisms, is increased by the presence of lime and to a lesser extent by fertilizers. Organic matter may be returned to the soil by the application of stable manure, crop residues, roots of crop plants, or by green manuring.

Organic matter plays an important part in soil fertility, the productive power of soils being largely proportionate to the amounts of organic matter present. The action of organic matter is along physical and biochemical lines. It improves the tilth of soils, their capacity to hold moisture, the aeration, and to some extent the temperature of soils.

The biochemical activities in soils result in the breaking down of the organic compounds, in making available to succeeding crops the minerals contained in the organic matter and in the transformation of nitrogen to nitrates.

The nature of the various groups of soil microörganisms has been pointed out and attention has been called to the fact that the reactions in soils may result favorably or unfavorably to crop plants. The available nitrogen of the soil may be consumed by soil microörganisms or may, under certain conditions, even be lost in the form of gaseous nitrogen.

Besides microörganisms especially active in decomposition and in the transformation of organic nitrogen to nitrates, there are in soils both symbiotic and non-symbiotic nitrogen-fixing organisms which can add to the store of soil nitrogen by fixing the nitrogen of the air.

The numbers of soil microörganisms vary widely, depending largely on the food supplies and other conditions. Under favorable conditions, nearly 400,000,000 bacteria alone may be present per gram of soil, but the number commonly present ranges from 2,000,000 to 20,000,000 per gram. The numbers of soil fungi are materially lower.

CHAPTER IV

THE NITROGEN PROBLEM

POSSIBLY no single problem in agriculture transcends this one in importance. Nitrogen is essential to all life and while it is not more essential than certain other elements, it is of outstanding importance because it is often present in insufficient amount, or in unavailable form. It is readily lost by leaching or otherwise, and is the most expensive element to supply in artificial fertilizers. While nearly four-fifths of the atmosphere is nitrogen and the supply is, therefore, abundant, crop plants are not able to use nitrogen in this form, but must get it through the soil, or through microörganisms living in the roots or leaves of the plant.

Nitrogen Content of Soils.—The nitrogen in soils is mostly in the form of organic nitrogen and is associated with the organic matter of soils. Small amounts of ammonia and fluctuating quantities of nitrates are present, but owing to consumption or loss by leaching, the accumulation of the latter, while occasionally considerable, is not as a rule large. In any event, both the ammonia and nitrates are derived from organic nitrogen compounds. The quantity of nitrogen in soils varies with the character of the soil, the treatment it has received, and with the quantities of organic matter in the form of manures, green manures, and crop residues that have been turned under. According to Lyon and Buckman, the soil nitrogen may range in surface mineral soils from .01 to .60 per cent. West Virginia soils, for example, may range from .043 to .539 with an average of .147 per cent, while Louisiana soils range from .001 to .109 with an average of .049 per cent. Muck and peat soils may contain as much as 3 per cent nitrogen.

TABLE XIV *

AVERAGE PERCENTAGE OF ORGANIC MATTER (C X 1.724) AND NITROGEN IN THIRTY REPRESENTATIVE MINNESOTA TILL SOILS FROM THREE SERIES

(The Figures for Each of the Three Soil Types are Averages of Ten Analyses)

DEPTH, INCHES	FOREST CARRINGTON LOAM		UPLAND PRAIRIE CARRINGTON SILT LOAM		LOWLAND PRAIRIE FARGO SILT LOAM	
	Organic Matter	Nitrogen	Organic Matter	Nitrogen	Organic Matter	Nitrogen
1-6	5.34	.253	7.96	.373	13.08	.616
7-12	2.41	.119	6.00	.285	8.00	.385
13-24	1.38	.078	3.11	.165	3.24	.150
25-36	.86	.041	1.31	.062	1.39	.054

* From Lyon and Buckman, Nature and Properties of Soils (copyrighted). By permission of The Macmillan Co.

The relation between organic matter content and nitrogen is brought out in the table on page 44 from Lyon and Buckman.

Most of the soil nitrogen is in the surface 9 inches, but on the Rothamsted Station appreciable amounts were found as far down as 90 inches. The amount, however, decreases as greater depths are reached. The following table prepared from data by Dyer shows the percentage of nitrogen found at various depths on Broadbalk Field, Rothamsted Experiment Station:

TABLE XV

PER CENT OF TOTAL NITROGEN AT DIFFERENT 9-INCH DEPTHS

(Averages of 21 Plats for the 1st, 2d, and 3d Depth, 12 Plats for the 4th to 8th, and 4 Plats for the 9th and 10th, 9-Inch Depths)

1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
.1222	.0784	.0666	.0511	.0472	.0430	.0420	.0396	.0391	.0375

Alway, as quoted by Lyon and Buckman, has determined the nitrogen in surface and subsoil of two Nebraska soils:

TABLE XVI

COMPARATIVE COMPOSITION OF SEMI-ARID (WAUNETA) AND HUMID (WEEPING WATER) LOESS SOILS OF NEBRASKA. (ALWAY)

DEPTH	ORGANIC MATTER (Percentage)		HUMUS (Percentage)		NITROGEN (Percentage)	
	Wauneta	Weeping Water	Wauneta	Weeping Water	Wauneta	Weeping Water
1st foot	2.77	4.98	1.02	2.34	.136	.236
2d foot	1.38	3.02	.65	1.29	.082	.154
3d foot	1.09	1.38	.48	.55	.065	.083
4th foot	.79	.83	.34	.27	.046	.059
5th foot	.55	.45	.26	.23	.038	.043
6th foot	.45	.36	.26	.19	.030	.038

The most rapid decline in the percentage of nitrogen in both the Rothamsted and Nebraska soils occurs in the second foot, while the decline at further depths is more gradual.

Loss of Nitrogen in Soils.—It has already been shown that cultivated soils lose humus, and with this loss of humus goes a loss of nitrogen. Part of this lost nitrogen is taken up by crop plants or by soil microörganisms and is consequently not a real or permanent loss; but by far the larger part escapes either in the drainage water or as free nitrogen, according to the conditions prevailing in the soil. That virgin soils are richer in nitrogen than similar soils long cultivated was shown by Thatcher (see Table I). This fact has been brought out by many workers and for many soils, and it has been shown that cultivation and cropping, especially without practicing a rotation that will insure the return of organic matter, is the great cause of the loss of nitrogen. Snyder has shown that some Minnesota soils have, in the course of twenty years of cropping, lost as much as 3000 to 5000 pounds of nitrogen per acre, only 900 of which was removed by the crops grown. About 2500 pounds of nitrogen per acre in twenty years was, therefore, a net loss.

At the Rothamsted station, where exact records are available for many years, the following differences in the nitrogen content of the soil were noted:[321]

TABLE XVII	Nitrogen in the First 9 Inches, Per Cent
Old pasture	0.250
Arable land in ordinary culture	0.140
Wheat unmanured 38 years	0.105
Wheat and fallow unmanured 31 years	0.096
Barley unmanured 30 years	0.093
Turnips unmanured 25 years	0.085

Loss of Nitrogen is Greatest in First Years of Cultivation.—It has been found that the greatest losses of nitrogen take place in the first few years of cultivation, the most readily available nitrogen being first consumed. Afterwards the decline is slower as the less readily available nitrogen in the humus is slowly liberated. The yields of crops grown on such soils at first decline rapidly; later, when the most readily available nitrogen is exhausted, low but nearly uniform or slowly declining yields result.[239]

Loss of Nitrogen by Leaching.—In common arable, not swamp soils, practically all the nitrogen lost from the soil, not including that removed in crops, is lost by leaching as nitrates. Nitrates are carried down by the percolating water and removed in the drainage. On ordinary farm fields it is difficult or impossible to determine the loss of nitrogen that takes place in this way, but at various experiment stations careful tests have been made by collecting the drainage from tile-drained fields or by means of specially constructed tanks known as lysimeters, by means of which the drainage from a known area can be accurately collected and the water analyzed for nitrates. The oldest of the drained fields exists at Rothamsted, where the drain pipes on Broadbalk field continuously cropped with wheat for fifty years and on which the plats have been variously fertilized, are so arranged that the drainage water from each plat can be collected separately. Here the annual loss of nitrogen on the plats cropped and fertilized for fifty years varied from 44 to 69 pounds of nitrogen per acre. The drain pipes, however, discharge only a fraction of the total drainage, and hence the loss is doubtless considerably higher than here recorded. Loss of nitrogen in the drainage was found to be heaviest from July to October, when the nitrates accumulated during summer were washed down. Since the amount of drainage will vary with the rainfall, periods of heavy precipitation are characterized by especially heavy losses of nitrogen in the drainage water. This point is of great importance in the southern states where heavy late fall and winter rains often follow a relatively dry late summer. During the summer there is a great accumulation of nitrates, most of which are likely to be washed away by the winter rains unless the ground is covered with a growing crop.

Loss of Nitrogen Shown by Lysimeters.—At several experiment stations lysimeters have been constructed so that more accurate studies could be made of the plant nutrients carried down by drainage. At Cornell University,[186] a crop rotation of maize, oats, wheat and timothy was established on all tanks except two which were left uncropped. The drainage water was analyzed for nitrogen and it was found that 17 times as much nitrogen was lost in the drainage from the uncropped as from the cropped tanks. The percolation of water was also greatest from the uncropped tanks, 78.35 per cent of the rainfall being recovered as drainage from the uncropped and 54.46 per cent from the cropped tanks.

Percolation varies with a number of factors, two of which are rainfall and evaporation. During the summer when the rate of evaporation is high, percolation and consequently the amount of nitrogen carried away in the drainage water is low, while with a reduced rate of evaporation and heavy rainfall the percolation increases. These facts all have an important bearing on practice in sections where the ground does not freeze in winter and where heavy rainfall and little evaporation during the cool months permits the percolation of a large amount of rainfall, especially on uncropped land. Fraps found that in Texas the loss of nitrogen as indicated by lysimeter, studies varied from an average of 67.2 pounds per acre per year for several sandy soils to 168.6 pounds for clays.

Bennett [12] has calculated that "the annual loss of plant food material due to washing away is approximately 126,000,000 pounds as compared with 5,900,000 pounds permanently removed by crops." The food material here referred to includes not only nitrogen, but all plant-food materials, but the calculation shows the vastly greater loss by erosion from uncropped surfaces than by the removal of crops.

Not all workers are agreed, however, as to this relation between loss by leaching and washing and by cropping. Whitson and associates state that, as a result of a study of Wisconsin farms long occupied and of virgin soils of similar character, they found that "the loss by leaching and denitrification amounts to only 22.3 per cent of the amount of nitrogen removed by crops."

Loss of Nitrogen in Cropping.—Lipman and Blair [177] have conducted at the New Jersey Agricultural Experiment Station an experiment in which crops were grown in cylinders. The nitrogen content of the soil was determined at the beginning of the experiment, all crops were analyzed and the nitrogen added as fertilizers was noted. A five-year rotation of corn, oats, wheat and timothy was established and the soil was again analyzed at the end of each rotation. Later a legume green manure was introduced on some of the cylinders, but for the first fifteen years the loss of nitrogen from the soil exclusive of that removed by the crops was found to be 103 pounds per acre annually. This is a large loss and is equivalent to 658 pounds commercial nitrate of soda per acre. In these rotations the ground was bare two winters out of five. While the drainage water was not collected, the nitrogen lost from the soils used in this experiment was doubtless mostly carried away by leaching.

At this point it may be well to emphasize the fact that losses of nitrogen are due almost entirely, if not wholly, to biochemical activities in the soil. Some of the nitrogen in plants turned under is directly utilized by the microörganisms, some is converted into nitrates which may be used by bacteria, or by crop plants, or may be lost by leaching. The consumption of the soil nitrogen cannot be stopped and it would be undesirable if it could, because it is only through biochemical action that it can be made available to plants. The net loss of nitrogen as nitrates may, however, be modified to a large degree and there is no better way to avoid these losses than by keeping the ground covered with a growing crop during all the time that nitrates are being produced and after they have accumulated.

Gain in Nitrogen.—On the other hand, the supply of nitrogen in soils may be maintained by adding organic matter. Whether this is done by means of stable manure, crop residues, or green manures, is a matter of economics; the same result may be attained by any of these methods. In 1902, Dyer reported that on the Broadbalk wheatfield of the Rothamsted Station, plot 3 had been continuously cropped, plot *2*[a] had been heavily manured for nine years, and plot *2*[b] for fifty years. The percentage of nitrogen in the surface 9 inches of the three plots was .0992, .1628, and .2207, showing the considerable accumulation of nitrogen as a result of manuring. After five years of growing cowpeas, soybeans and vetch, the last named as a winter crop, Hart-well and Pember[105] found that the soil was enriched to the amount of 120 lbs. of nitrogen per acre per year. In this case the vetch alone was turned under, the cowpeas and soybeans were removed. Thornber,[288] in Montana, seeded clover in an apple orchard in May and turned it under in the fall of the following year. At the end of eight years the clean cultivated plat, contained 1514 pounds nitrogen in the first 2 feet of soil, and the clover plat, 3019 pounds. The accumulation of nitrogen when nothing is removed from the soil was shown by Shutt to be 511 pounds per acre in ten years, during which clover was grown, and allowed to decay in place. Analyses of the clover showed that the clover, stems, leaves and roots contained upwards of 100 pounds of nitrogen each year so that only one-half of this went to enrich the soil in nitrogen. In this case there was a considerable loss of nitrogen, which might have been saved by appropriate cropping or feeding.

In Little Hoos Field at Rothamsted, one year's growth of clover on land cropped to grain for some years left the surface 9 inches 0.015 per cent richer in nitrogen than another part of the same field cropped to barley. In this case the clover was removed.[321] When crops have been heavily supplied with artificial nitrogen fertilizers the root growth may be stimulated and the nitrogen content of the soil may actually increase, owing to the storing up of this fertilizer in roots and stubble. Thorne has expressed the view that the sole function of stable or green manure is to carry food materials, especially nitrogen, and has ignored any other benefits the soil is supposed to derive from organic matter. While it is true that the heavy use of nitrogenous fertilizers may so stimulate root growth as to store enough nitrogen to increase the total nitrogen content of the soil, this can scarcely be considered an economical practice.

Lipman and Blair [174] found that the annual application of 160 pounds of nitrate of soda per acre in their cylinder experiments did not maintain the soil nitrogen, but that the use of green manure crops between main crops increased the nitrogen content of the soil by 33.33 pounds per acre per year through the experiment, besides producing heavier crops than any other treatment.

As a result of the lysimeter experiment mentioned on p. 47, Lyon and Buckman have determined the losses of nitrogen and organic matter due to cropping and drainage and have shown how these losses may be made good by the use of stable manure and green manures. The results are shown in Table XVIII, adapted from Lyon and Buckman.

TABLE XVIII *

LOSSES AND ADDITIONS OF NITROGEN AND ORGANIC MATTER THAT MIGHT OCCUR TO DUNKIRK SILTY CLAY LOAM UNDER A FIVE-YEAR ROTATION.

(Expressed in Pounds to an Acre a Year)

	Nitrogen	Organic Matter
Reductions when farm manure and green manure are not used.	40.3	1200
Additions from farm manure	21.1	1000
Additions from green manure	20.0	600

* The figures given by Lyon and Buckman for nitrogen and organic matter only are given in this table. By permission of The Macmillan Co. (copyrighted).

In this calculation, the crops grown are supposed to have been fed, the manure returned, and a green manure crop used once in five years. It is of interest to note that if such a green manure crop, estimated to yield 3000 pounds per acre of soil organic matter, could be turned under twice in five years the nitrogen and organic matter in the soil could be maintained. In regions permitting of the growing of winter green manure crops such a rotation is entirely practicable.

While the growing of crops is always and unavoidably accompanied by the loss of the soil nitrogen, partly by being used by the growing crop, but more largely by leaching, it is possible to make good such losses and to maintain the soil nitrogen at a level that will insure maximum crops.

Nitrates are Most Available to Crop Plants.—While it is known that nitrogen as ammonia can be utilized by plants, there is no doubt that for the greater number of crop plants nitrate is more readily available than ammonia. Barley can use ammonium sulphate when nitrifying organisms are absent, but Fred [72] has shown that greater growth is made when the ammonium sulphate is nitrified. He grew barley in pure

washed quartz sand and added ammonium sulphate to one set of pots, while the other set received ammonium sulphate and nitrifying bacteria. After 120 days the weight of plants was:[1]

	Grams
Pots without nitrogen............................	1.5
Pots with ammonium sulphate....................	66.5
Pots with ammonium sulphate -+- nitrifying organisms.	116.0

Nitrates, being readily soluble, are quickly leached away and it is, therefore, important that the turning under of organic matter should, as far as possible, be done so that the resulting decomposition may provide nitrates at a time when the crop is making its most vigorous growth.

Ammonification.—In the decay of organic matter, some of the nitrogen is set free as ammonia and this process is called ammonification. Ammonia is a by-product of the life activities of soil microörganisms, both bacteria and fungi, and the quantity measured in any case is only a part of that produced, unknown amounts being consumed by soil microörganisms. When the organic matter at the disposal of microörganisms is very rich in carbohydrates and when nitrates are available, the energy demands and nitrogen requirements of the microörganisms may be supplied with but little release of ammonia, hence the importance of turning under material relatively high in nitrogen rather than such material as straw, which is poor in nitrogen.

Many species of bacteria, as well as fungi and other microörganisms, are able to produce ammonia so that the process goes on under a great variety of conditions, although best in a well-aerated soil and with enough basic material present. Fungi usually prefer a more acid soil reaction and it has been shown that several common soil fungi are active producers of ammonia.

Soils vary in the promptness with which ammonification takes place in them and in the completeness with which organic substances mixed with such soils are ammonified. This property is spoken of as the ammonifying power of the soil and many studies have been made along this line. It has been assumed that the ammonifying power of a soil is an index to the richness of the bacterial flora, but in view of the known

[1]From Soil Science [17]: By permission of The Williams and Wilkins Co., Baltimore.

importance of soil fungi, it is not possible in all cases to ascribe the major role to bacteria.

Influence of Conditions on Ammonification.—Ammonification takes place at a wide range of temperature. Coleman [43] found no ammonia produced at 6-8° C. and below, at 20° C. the production of ammonia was marked. The optimum temperature was found to be 30° C, and a decline set in at 38° C.

Moisture is necessary, but this too may vary through a considerable range. Coleman [43] found that some fungi produced ammonia in soil with 7 per cent moisture, but that most species displayed greatest activity with the moisture content from 14 per cent to saturation, at which point the production of ammonia declined sharply. Many workers have found that calcium carbonate increases ammonification, as well as the numbers of bacteria. This is also the case when soluble phosphates are applied, but Fred and Hart found that, while soluble phosphates increased the production of ammonia as much as 290 per cent in two days, the increase in ammonia production was not proportional to the increase in numbers of bacteria. The phosphate had stimulated the reproduction, rather than the efficiency of the organisms. With the great variety of organisms that are capable of producing ammonia, the production of this goes on under widely varied conditions. In laboratory studies on dried blood, peptone and similar substances, the appearance of ammonia has been found to be a matter of hours only, but when plant material is turned under the process is a more gradual one. No adequate studies are available to show how soon ammonification begins after plant material is turned under.

Nitrification.—While there are many organisms that can produce ammonia, it is interesting to note that there are but two organisms definitely known to change this ammonia to nitrates, a process vitally important to plant life. These two organisms can each attack only one substance and produce but one product. Nitrosomonas (or nitrosococcus) can use ammonium carbonate only,[242] and as a product of its activity, leaves nitrous acid which, combining with a base, produces a nitrite. This is further oxidized by Nitrobacter, with the production of nitric acid and nitrates. Both processes are so nearly coincident that commonly very little nitrite is found in soils. Nitrification is a more rapid process than ammonification, and, consequently, the latter is the limiting factor in determining the rate of nitrification in soils. The change from ammonia nitrogen to nitrate nitrogen is nearly quantitative, the organisms themselves using very little nitrogen. Fortunately, the nitrifying bacteria are widely distributed and, though easily killed by heat and extreme drought, readily appear again when conditions are favorable. While nitrification is most rapid in the surface foot, nitrifying bacteria have been found present at a depth of 105 and 135 cm., 42 and 54 inches, and King and Whitson,[148] found considerable quantities of nitrates at a depth of 4 feet.

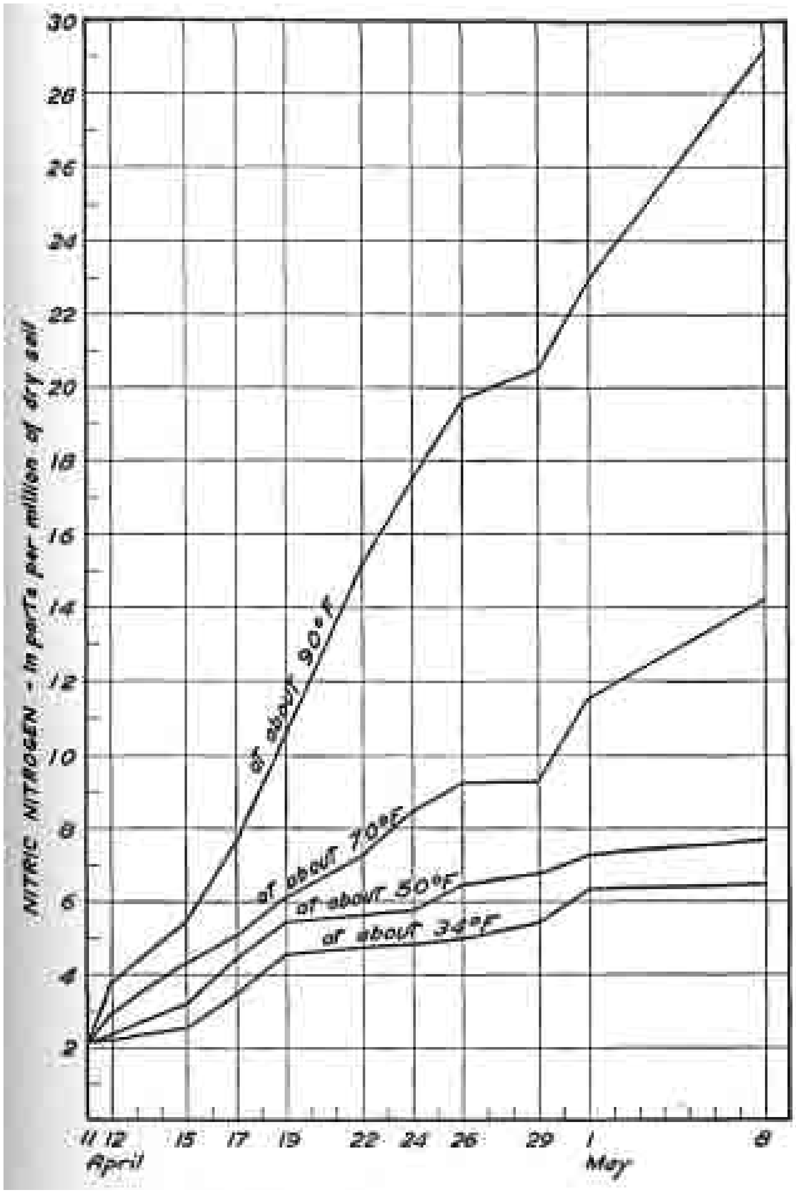

FIG. 9.—The amount of nitrate produced in a given time increases with temperature. (Redrawn by L. W, Kephart from King and Whitson, Wis. Agr. Expt. Sta. 18th Ann. Rpt. 1901.)

Conditions Affecting Nitrification.—At 5° C, nitrification is feeble or wanting, is perceptible at 12° to 15° C, most rapid at about 35° to 37° C. and stops at 55° C. Hall,[94] however, states that nothing but absolute freezing stops the production of nitrates, and King and Whit-son [151] report work showing that some nitrification took place at 34° F. (1.1° C). At higher temperatures, however, there was a rapid rise in the quantity of nitrate produced in a given time. This is graphically shown in Fig. 9.

Moisture is necessary and in general that percentage of moisture which is the optimum for the soil in question is also the optimum moisture condition for nitrification. While there is, therefore, some latitude in the moisture requirement for nitrification, Gainey, studying a Kansas soil, found that "an increase of 1 per cent moisture at or near the minimum for nitrification may cause an increase of 100 per cent in nitrate production."

Fig. 10 shows graphically the relation between moisture content of a soil and the production of nitrates.

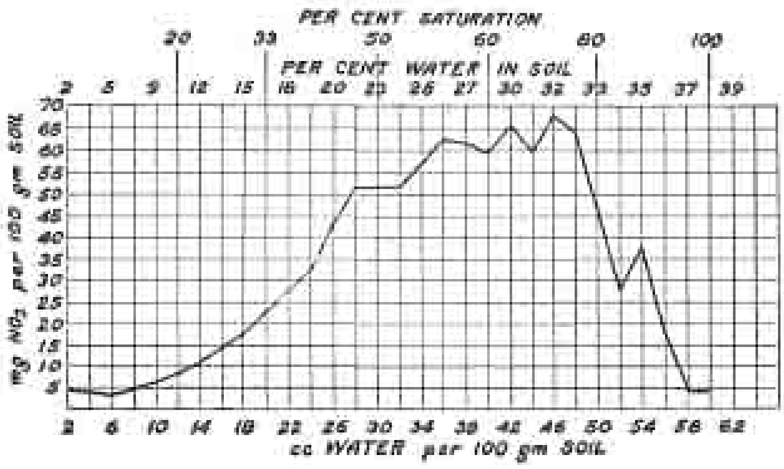

FIG. 10.—Nitrification is most active in moist soil.
(Redrawn by L. W. Kephart from Gainey, Soil Science, 1916.)

The quantity of nitrates produced at a given temperature and soil moisture may vary with the soil type. Russell, Jones and Bahrt found that a soil from Western Nebraska produced as much nitrate in three weeks at 5° C. as a soil from Eastern Nebraska produced at 20° C. in the same time. The Western Nebraska soil further produced as much nitrate in seven days with a soil moisture of 12.5 per cent as that from Eastern Nebraska did in twenty-two days with a soil moisture of 25.6 per cent.

Besides heat and moisture, oxygen is essential. The value of an abundant supply of oxygen is shown in an experiment by Gowda, who found that without aeration of his culture solution, one week was required to oxidize 25 c.c. of the solution, while, when the solution was aerated, 1000 c.c. of the same solution was oxidized in one week. In properly moist soils, oxygen is always present, no matter how compact these soils are, so long as they are not saturated with water. Gainey and Metzler studied the effect of compacting a soil on nitrate accumulation and found that unless the soil was too wet, no degree of compacting they could give had any adverse effect on the accumulation of nitrates.

In culture solution, nitrifying bacteria have been found very sensitive to the presence of organic matter and acids and from this fact the conclusion was drawn that there could be no nitrification in acid soils. This is not the case, however, Temple,[282] Given and Kuhlman,[84] Fred and Graul,[75] White, [327] and others in this country, T. D. Hall, in South Africa, and A. D. Hall and associates in England have found nitrification going on more or less freely in very acid soils, and A. D. Hall and associates have suggested that possibly small particles of calcium carbonate form nuclei around which nitrification can take place. Lime has frequently been found to stimulate nitrification, but in soils the process can evidently go on in the presence of less lime than that needed to produce a neutral reaction. This phenomenon has not been adequately explained. Organic matter has been found beneficial in soils, and phosphates are needed for the best results.

Seasonal Changes in Nitrate Accumulation.—It has been found that nitrate accumulation starts rapidly with the advent of spring, rises to a maximum some time in the summer, the time depending on crop and conditions, falls when the crop is most actively growing and rises again in the fall. King and Whitson [151, 152] found that in soil planted to corn and to potatoes, the peak of nitrate accumulation was reached about July 1st, while under clover, oats and alfalfa, the peak was reached June 1st. Fig. 11, from King and Whitson, shows graphically the course of nitrate accumulation from April 1st to November 29th, the curves in the figure having been extended from the King and Whitson data beyond the dates shown in their figure. Russell [242] found at Rothamsted that different soil types showed great variation in nitrate accumulation. One of Russell's curves reproduced in Fig. 12 shows nitrate accumulation in fallow soils or those bearing young fruit trees. It must be remembered that all of these curves represent nitrate accumulation and not production. They show the balance left after the nitrates used or lost have been deducted from those produced.

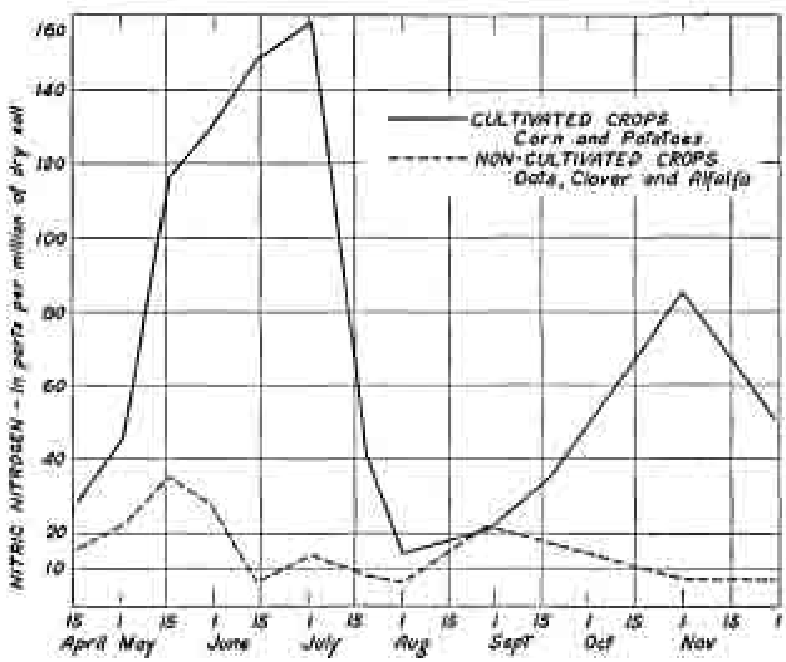

Fig. 11.—Nitrate accumulation varies with the season as well as with the crop grown. (Drawn by L. W. Kephart from data in Wis. Agr. Expt. Sta. Bul. 85.)

Effect of Cropping on Production of Nitrates.—It is known that, other conditions being equal, greater quantities of nitrates accumulate in fallow than in cropped lands. A part of this difference is naturally due to the nitrates absorbed by the crop, but Russell [241] has pointed out that, during late summer and early fall, the nitrate content of fallow land is larger than that of cropped land, even after allowing for the nitrogen removed in the crop. It appears from his work that the *production* of nitrates is less under crops than in fallow land. The explanation of this phenomenon, if it be general, is not clear.

Effect of Tillage, Lime, Gypsum, and Fertilizers on Ammonification and Nitrification.—Since a good supply of oxygen is essential to the life of the nitrifying bacteria, tillage is of value as insuring thorough soil aeration. The difference between the nitrate content of cropped land, in one case in a tilled, in the other in an untilled, crop is graphically shown in Fig. 11.

Lime has already been shown to be beneficial to both ammonification and nitrification. Greaves showed that *calcium sulphate (gypsum)* in low to medium concentrations, stimulated ammonification, while Wollny quotes Picard as having observed very energetic nitrification as a result of an application of gypsum. Phosphates and to a less extent potash, stimulate the development of soil organisms and increase ammonification, but nitrates, except in some cases of low concentration, appear to depress ammonification. Nitrification is decidedly depressed by the presence of large amounts of sodium nitrate.

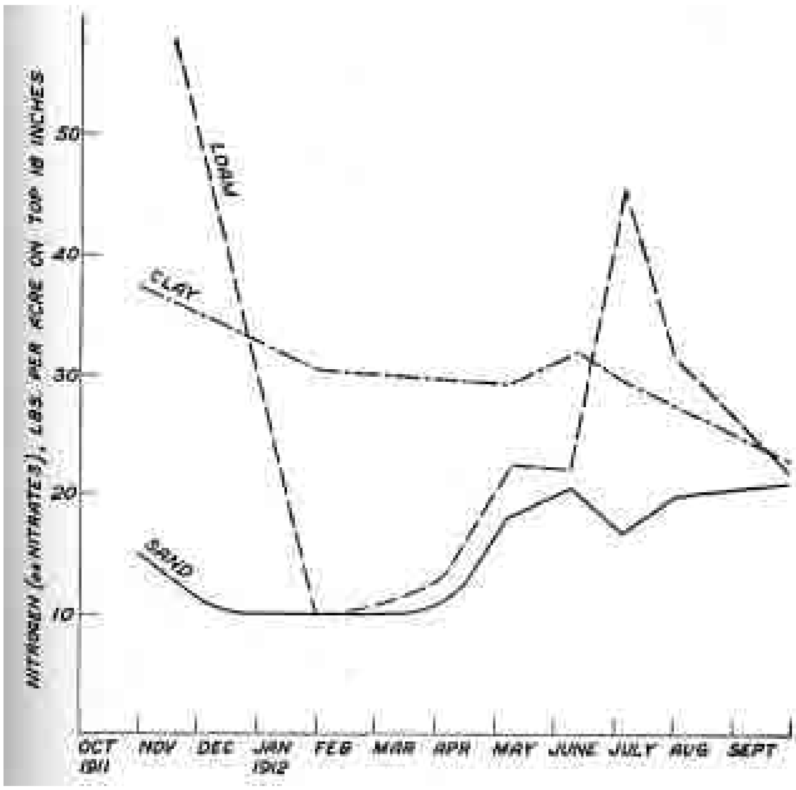

FIG. 12.—Seasonal changes in nitrate accumulation may vary with soil type. (Redrawn by L. W. Kephart from Russell, Soil Conditions and Plant Growth.)

Relation of Bacterial Numbers to Ammonification and Nitrification.— Because the production and oxidation of ammonia are biological processes, it has been argued that there must be a causal relation between the numbers of bacteria and the quantity of ammonia produced from organic matter, as well as the accumulation of nitrates. By inference, there has been assumed to be a relation between the number of bacteria and the fertility of the soil. Many workers have thought they were able to establish the correctness of these assumptions and believe themselves to have shown that ammonification and nitrification in, as well as the productive power of a given soil are causally related to the numbers of bacteria found. Waksman [314] believed that there is a correlation between the crop productivity of the soil on the one hand and the numbers of microörganisms and nitrifying capacity of the soil on the other. Russell [242] has also discussed this matter and quotes data from Keller man and Allen, showing that productive soils had a higher nitrifying capacity than unproductive soils, but in this case the bacterial numbers were greater in the unproductive than in the productive soil. That, other things being equal, soils with high nitrifying capacity should be most productive can be readily understood and since nitrification is the result of bacterial activity, productive soils probably contain more nitrifying bacteria than unproductive soils. A study of the considerations brought out by Doryland and the fact that not only bacteria but many fungi are active ammonifiers show, however, that there is little reason to expect a close correlation between mere bacterial numbers and soil productivity. Doryland has well brought out the point that bacteria require energy material and nitrogen. When the supply of energy material is large the ammonia produced from the protein molecule may be in part consumed by the very bacteria (or fungi) producing the ammonia; in some cases, even nitrates already present in the soil may be consumed. The quantity of ammonia left for nitrification and later use by crop plants is, therefore, only the residue of what microörganisms have not used. An abundant supply of energy material may cause an enormous increase in microörganisms without any increase in the ammonia left for nitrification. Since nitrification is a more rapid process than ammonification, the former can proceed only as fast as surplus ammonia is made available.

What has been said about the effect of energy material in increasing the numbers of bacteria is also true of the application of lime or phosphates. Conner and Noyes studied the effect of calcite, magnesite, and dolomite on the numbers of bacteria and also on the yields of wheat, clover, and beets, in acid clay and black sand. The table below, adapted from Conner and Noyes, shows that there is no relation between bacterial numbers and crop yields close enough to be considered causal.

TABLE XIX

Crop Yields in Grams per Pot and Bacterial Numbers as a Result of Treating an Acid Clay and an Acid Black Sand with Calcite, Magnesite and Dolomite

(Yields on Yellow Clay. Grams per Pot)

	Wheat	Clover	Beets		Bacterial Counts, Millions.
			Tops	Roots	Total
1. Control .	44.0	2.0	0	0	3,027
2. 4,000 lbs. calcite	66.5	18.5	33.0	18.0	7,605
3. 4,000 lbs. magnesite	64.0	16.0	53.0	33.0	13,669
4. 4,000 lbs. dolomite	62.5	20.0	44.5	22.5	
5. 12,000 lbs. calcite	77.5	15.5	56.5	49.5	5,244
6. 12,000 lbs. magnesite	71.0	16.5	63.0	51.5	10,291
(Yields on Black Sand. Grams per Pot)					
1. Control	1.5	3.5	0	0	5,720
2. 4,000 lbs. calcite	31.5	12.5	23.0	13.5	10,682
3. 4,000 lbs. magnesite	29.0	8.5	51.0	23.0	7,253
4. 4,000 lbs. dolomite	35.5	11.5	33.0	21.0	
5. 12,000 lbs. calcite	51.0	15.0	50.0	21.0	17,797
6. 12,000 lbs. magnesite	0	0	3.0	.5	6,462

In the course of a study on the influence of stall manure upon the bacterial flora of the soil, Temple recorded the bacterial numbers and ammonifying efficiency for several soils during spring and summer. The following table presents a small part of the data given in Table XXX of Temple's paper and will serve to illustrate the statement that there is no necessary relation between the numbers of bacteria and the ammonifying efficiency of a given soil.

Briscoe and Harned claim to have shown in their experiments a relation between bacterial numbers and crop yields, but their evidence is unsatisfactory. Russell and Appleyard have plotted curves showing bacterial numbers and nitrates found in soils and conclude that these phenomena are related.

While it is true that the production of nitrates depends wholly on biological processes, the bacteria found on culture plates are not confined to those responsible for nitrification and, since the production of ammonia on which nitrification depends is not solely a function of bacterial activity, too close a correlation between bacterial counts and the production of nitrates is not to be expected.

TABLE XX
BACTERIA PER GRAM OF DRY SOIL AND AMMONIFYING EFFICIENCY,
N AS NH_3 (PARTS PER MILLION),
(From Table 30. Temple)

	Bacteria, 000 Omitted		Ammonifying Efficiency	
	Soil 326. No Manure	Soil 326*a*. With Manure	Soil 326. No Manure	Soil 326*a*. With Manure
March 26, 1909	1220	1,220	219.3	....
April 1, 1909	1633	4,300	222.8	200.1
April 9,1909	6120	18,000	210.8	234.4
April 15. 1909	3780	10,000	237.1	233.4
April 22,1909	2730	5,260	227.2	245.5
April 29, 1909	2770	3,340	210.6	214.1
May 6,1909	5510	5,190	213.6	219.0
	Soil 470. No Manure	Soil 470*a*. With Manure	Soil 470. No Manure	Soil 470*a*. With Manure
May 9,1909	2227	2,227	192.0	....
May 13,1909	3780	6,000	205.3	222.2
May 20,1909	6540	13,000	197.5	242.5
May 27,1909	6750	11,690	268.1	283.2
June 5,1909	7700	24,000	303.4	296.8
June 10, 1909	3630	8,560	248.1	261.9
June 17,1909	4270	6,330	225.2	283.6
August 12, 1909	3800	7,850	302.5	308.8

While the supply of nitrogen in a form available to crop plants depends on biological processes, the actual crop yields secured depend on a complex of conditions and some of these may be of minor importance for the bacterial flora. A fertile soil naturally contains more microörganisms than an infertile one, but a correlation between crop yields and the number of bacteria in a soil would appear to be due to the fact that soil microörganisms and crop plants are affected similarly by the prevailing soil conditions rather than that the fertility of the soil *depends* on the bacterial *numbers,* although it certainly does depend on biological processes.

Effect of Small Quantities of Stable Manure on Ammonification and Nitrification.—It has been observed both in the United States and abroad that when small quantities of stable manure are applied to green manures, before the latter are plowed down, the effect to be expected from the green manures may be materially enhanced. Lipman and associates [179] believed the observed phenomenon to be due to the large numbers of bacteria added to the soil with the manure. The same conclusion was reached by other workers in this country, as well as by some abroad, and most have believed the increased numbers of bacteria introduced with the manure responsible for the effect observed. Rahn, however, suggests that the manure merely adds nitrogen, which the bacteria can use and thus more readily decompose the green manure, while Lemmerman and associates [167] found no greater decomposition of organic matter when green and stable manures were decomposed together, than when each was treated separately.

SUMMARY

The nitrogen problem is believed to be the most important one in agriculture. The soil nitrogen is associated with the soil organic matter and, in surface soils, may vary from 0.01 to 0.60 per cent. While most of the soil nitrogen is in the surface layer, some is found at greater depths, even down to 90 inches.

Soil nitrogen is lost by cropping, some being removed by the crop plants, but the greater part is lost by leaching. When good virgin lands are first brought under cultivation, there is a large loss of nitrogen as the more readily available organic matter is decomposed by soil microörganisms. This early rapid decline is followed by a period of much slower decline, as the less available organic matter is slowly decomposed.

The nitrogen in soils can be maintained by appropriate cropping and manuring systems and especially by the culture of legumes and their utilization as green manures. One of the first products of the decay of nitrogenous organic matter is ammonia, which is a by-product of the life activities of many different soil microörganisms. This ammonia when not otherwise used is in turn transformed to nitrates and in this form is most readily available to the majority of crop plants.

The process of nitrification has been outlined and the conditions, as moisture, temperature, etc., that influence ammonification and nitrification have been discussed. The amount of nitrates accumulated in soil varies from season to season, being greatest in early summer, declining in mid-summer, and rising again in fall. These amounts represent the difference between nitrate production on one hand, and utilization and loss on the other. Nitrification is a more rapid process than ammonification and, consequently, the production of nitrates is controlled by the rapidity with which ammonia is produced.

The plowing under of large amounts of organic matter with a high carbohydrate and low nitrogen content such as mature rye, or straw, may result in the consumption by microörganisms of the available soil nitrates and in reduced crop yields. The turning under of leguminous material or any material relatively high in nitroge'n results in a release of ammonia which is converted into nitrates with resultant benefit to crop plants.

Because fungi, as well as bacteria, take part in the production of ammonia, it is not possible to show a close relation between the quantities of ammonia produced and the numbers of bacteria in soils. Neither can yields of crop plants be definitely correlated with bacterial numbers in the soil. There is no question, however, of the relation between the production of ammonia and nitrates and bacterial activities, but crop yields depend on other factors as well as on the presence of nitrates.

CHAPTER V

NITROGEN FIXATION

IT has been pointed out that, although nearly four-fifths of the atmosphere consists of nitrogen, this element is not available to crop plants in its gaseous form. Various workers have attempted to show that crop plants can use atmospheric nitrogen, but their results are not generally accepted. Even if the conclusions drawn from such experiments are correct, the amounts of nitrogen thus absorbed are so small as to be of no importance in agriculture.

Crop plants take their nitrogen in the inorganic form, which means that the gaseous nitrogen must first go through the organic form,[1] in other words, must first be fixed. The fixation of nitrogen is accomplished by microörganisms and, as far as certainly known, almost wholly by bacteria. Functionally, these fall into two classes: (1) those associated with plants, for agricultural purposes, chiefly legumes; and (2) those free-living bacteria able to use gaseous nitrogen.

Nitrogen Fixation through Legumes.—This process is sometimes spoken of as fixation by legumes, although this is not accurate. Without the proper bacteria, legumes are as unable as other plants to use or fix atmospheric nitrogen. In order that legumes may utilize atmospheric nitrogen, their roots must first be invaded by a rod-shaped organism known as *Bacillus radicicola.*

These bacteria work their way into the smaller roots or root hairs, causing the production of nodules of various shapes and sizes, depending on the host plant, Fig. 13, and assimilate free nitrogen. The nodules may sometimes attain considerable size as in the velvet bean, Fig. 14. It is not known just how the legume host gets the nitrogen, but it is known that in the presence of these bacteria, legumes can grow in soils devoid of nitrates.

Legumes have been grown in quartz sand wholly devoid of nitrogen, only the necessary bacteria and minerals being added. In such a case the legume took all its nitrogen from the air. The sweet clover shown in Fig. 15 growing in inoculated soil had at its disposal the nitrogen left by three previous crops of inoculated legumes as well as that from the air, but the first crop that grew on this sand had no soil nitrogen to draw on. However, legumes do not depend wholly on the nodule bacteria for their nitrogen, but absorb soil nitrogen compounds, chiefly nitrates, just as do other plants. The entire amount of nitrogen found in a legume growing in soil is, therefore, not taken from the air, as is sometimes stated.

An Epoch-making Discovery.— The discovery that legumes could use atmospheric nitrogen through the bacteria in the root nodules is one of the romances of agricultural science and is worth calling to the reader's attention to show that important discoveries are commonly the work of many men, each one adding a little, clearing up an obscure point here or there; sometimes drawing unwarranted conclusions to be corrected by later workers, and thus stimulating research, even though their own views are finally discarded.

[1] This naturally has no relation to artificial nitrogen fixation.

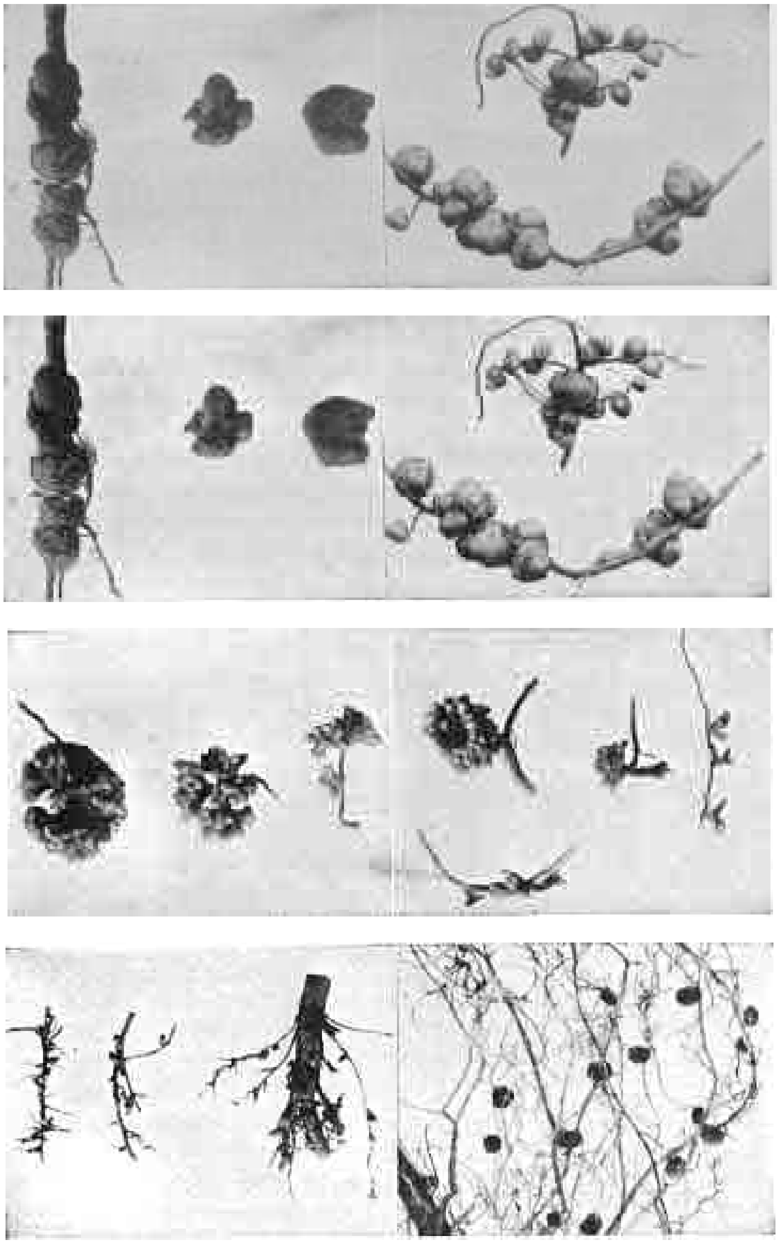

FIG. 13.—Legume nodules vary in size and shape. All figures to same scale.
(U. S. Department of Agriculture.)

FIG. 14.—Velvet beans nodules may attain large size. Scale same as Fig. 13.
(U. S. Department of Agriculture.)

FIG. 15.—Inoculated legumes may get their nitrogen from the air. The sweet clover at the right represents the fourth crop of inoculated sweet clover grown on nitrogen-free pure sand. That at the left represents the fourth attempt to grow the plants on similar sand but without inoculation.
(Wisconsin Agricultural Experiment Station.)

Early in the nineteenth century, scientists became actively interested in plant nutrition and it was soon evident that nitrogen was an important food element. Many studies were made and theories propounded as to how plants get this nitrogen, until finally Boussingault, in 1854, appeared to have shown conclusively that plants could not use the nitrogen in the air. The fact remained, however, that legumes could grow on soil so poor that rye made but a poor crop, and further, that legumes did enrich the soil as had been known by practical men for ages. How was it done? Even at Rothamsted, where Boussingault's experiments had been repeated and confirmed, the question could not be considered as finally answered. In America, Atwater grew peas and found that the peas contained more nitrogen than had been removed from the soil. Other workers also frequently found clover or peas growing luxuriantly in their nitrogen-free cultures. It was clear that legumes did get nitrogen from the air, but how? Meanwhile, various workers studied the nodules and found bacteria in them, but did not connect these with the nitrogen supply of the legumes, although the importance of bacteria was coming to be understood. As early as 1817, Von Wulffen had called attention to the nodules on lupines and later others showed that these were present on all common legumes.

Hellriegel and Wilfarth, two German botanists, were among those studying this question, and they could not fail to observe that, while their experiments with grains always resulted as expected, those with legumes had variable results. Sometimes the peas grew well, sometimes not. Often the peas in nitrogen-free media were feeble for a few weeks and then began a rapid growth, overtaking those supplied with nitrates. Hellriegel and Wilfarth knew that Berthelot had shown that free living bacteria in soil could fix nitrogen, but that when the soil was sterilized no nitrogen was fixed. They knew also that bacteria or bacteria-like bodies had been found in legume nodules first by Woronin and then by Beijerinck. They reasoned, therefore, that if the legumes got this nitrogen through these nodules, the addition of a soil solution in which there would be bacteria should ensure healthy growth for the peas, but not for the grains, and that in sterile nitrogen-free soil the peas, as well as the grains, would die of nitrogen hunger. The results justified the hypothesis; the grains perished in nitrogen-free cultures, in spite of the addition of soil solution, while when the soil solution was added the peas developed root nodules and grew lustily but remained free from nodules and perished when grown in sterilized nitrogen-free sand without soil solution. Later, these conclusions were confirmed and extended by other workers and the question, how legumes get their nitrogen, was solved.

How Much Nitrogen is Fixed through Legumes.—A great deal has been written about the amount of nitrogen fixed through legumes, but most of this work is of doubtful value. Many popular writers have given the total amount of nitrogen found in a legume crop and have assumed that this is all gain but, as pointed out, this is not correct. The more careful attempts to determine how much of the nitrogen in legumes comes from the air may be considered in two classes. Some have determined the nitrogen in a legume without root nodules and have compared this with the nitrogen found in noduled plants grown in similar soil. Others having worked more carefully have determined the nitrogen in the soil at the beginning of the experiment; that added in seeds, and fertilizers; that removed in crops; and that left in the soil at the end of the experiment. The results vary so widely that no general average can be given, but it will be instructive to discuss some of the more important work.

Before proceeding with a study of the work done along this line, the great potential importance of legumes as a source of nitrogen may be pointed out. Whiting and Fred have calculated that if no more than 50 pounds of nitrogen per acre were fixed in this way and 10 per cent of the cultivated land in the United States were planted to a legume crop, 925,000 tons of nitrogen would be added to the soil every year. Since the total amount of nitrogen used in commercial fertilizers annually is only 200,000 tons, the great importance of an increased legume area is at once apparent. As will be made clear later, the growing and removing of annual legumes will not help greatly in adding this nitrogen, but this can be secured in part by turning under a second crop of red clover, or by using sweet clover, vetches and summer legumes as green manures.

Comparison of Inoculated and not Inoculated Legumes.—Hopkins [123] considered this method a safe one, though he recognized that the stronger root system of the inoculated plants might take more nitrogen from the soil than was taken by plants not inoculated. By this method, inoculated alfalfa plants were found to have taken 64 per cent of their nitrogen from the air. In another case,[122] cowpeas were found to have taken 73 per cent of their nitrogen from the air. From consideration of some work with sweet clover, Hopkins [123] also concluded that this crop secured two-thirds of its nitrogen from the air.

Alway and Pinckney determined the nitrogen in field-grown alfalfa plants, some inoculated, others not inoculated. Assuming that the excess of nitrogen carried by the inoculated plants over those that were not inoculated came from the air, then these plants took 40 and 52 per cent of their nitrogen from that source. Arny and Thatcher found less difference in the composition of inoculated and not inoculated alfalfa plants than might have been expected, but the yields were much better from the inoculated plants and these had fixed from 10 to 48 pounds of nitrogen per acre. In one case, calculations based on plants cut from several square yard areas showed a fixation of 118 pounds per acre. Sweet clover fixed 76 pounds on unlimed soil and 133 pounds on limed soil.

Fred and Graul [74] found that, on limed soil, inoculated alfalfa fixed, in one case, 59 pounds, in another, 81 pounds, and again 269 pounds nitrogen per acre in tops alone. On limed Colby silt loam, red clover fixed 62 pounds and on Sparta sand, 145 pounds per acre. Fred,[71] in a later work, found that soybeans grown on Plainfield sand and well inoculated, had taken 87 per cent of their nitrogen from the air. He calls attention to the fact which becomes clear to those who study the work done on this subject, that the amount of nitrogen which legumes can get through their nodules will vary with completeness of inoculation, soil type, temperature, moisture, etc. Smith and Robison studied soybeans and cowpeas by this method. The plants were grown on a fertile loam, but the inoculated soybeans contained 113.55 pounds nitrogen in roots and tops, while those not inoculated contained 75.98 pounds per acre. The yield was higher from the inoculated plants and calculated on pounds of nitrogen per ton, the inoculated soys had taken 26 per cent of their nitrogen from the air.

Nobbe and Richter, in the course of a study of the effect the presence of nitrates would have on bacterial nitrogen fixation in legume nodules, concluded that with no nitrates present inoculated hairy vetch plants took 93.8 per cent of their nitrogen from the air. In the presence of an abundant supply of nitrates, this percentage was reduced to 79 and 73 per cent. It will be noted that, in general, the above records sustain Hopkins' contention that on the average well-inoculated legumes may take about two-thirds of their nitrogen from the air.

In a few cases, the nitrogen found in an inoculated legume has been compared with that in a grain growing on similar soil. Duggar [54] found that rye growing on a poor soil contained 26 pounds nitrogen per acre, while well-inoculated hairy vetch contained 105.5 pounds and crimson clover 143.7 pounds. Without inoculation, neither of these legumes was able to extract enough nitrogen from the soil to make more than a feeble growth, and Duggar believes the inoculated legumes must have taken at least three-fourths of their nitrogen from the air. Similarly, Lipman and Blair [17S] calculated from the amounts of nitrogen secured by alfalfa and by various grain crops growing on similar land, that the alfalfa had drawn on the supply of atmospheric nitrogen for 150 pounds out of the 200 delivered in the hay crop from an acre in one year. The percentage of nitrogen in the alfalfa was found to be increasing each year, and so there was evidently no soil depletion. Along somewhat different lines, Lyon and Bizzell[185] found that after six years of alfalfa and and six years of timothy, the soil under the alfalfa plants contained 200 pounds of nitrogen per acre more than that under the timothy.

At Rothamsted, red clover was grown on part of a field that had been six years in wheat, the other part of the field was seeded to barley. The clover removed 150 pounds of nitrogen in the crop, but still left the soil to a depth of 9 inches about 450 pounds richer in nitrogen than the barley field.

Determining the Nitrogen Gain by Chemical Analyses of Soil and Crop.—One of the earliest studies along this line was that by Atwater and later by Atwater and Woods. This work was commenced before the relation between bacteria and the ability of legumes to utilize atmospheric nitrogen was understood and was undertaken to show that somehow legumes could use the nitrogen in the air. The nitrogen in the sand, the seed and the fertilizers was carefully determined, as well as that in the peas harvested and in the sand at the close of the experiment. In one case, it was shown that peas with many nodules contained 648.4 milligrams of nitrogen, but that they had removed only 266.3 milligrams from the pots and had thus taken more than half their nitrogen from the air. Kristensen, in Denmark, found that green manuring with lupines for several years had increased the nitrogen content of the soil from .046 to 0.062 per cent.

Hartwell and Pember [105] grew legumes exclusively for five years, soybeans and cowpeas in summer, and hairy vetch in winter. The summer crops were removed, but the hairy vetch was turned under. At the end of the five years, the *gain* in nitrogen for the pots carrying soybeans and cowpeas was found to equal a ton per acre. Seven-tenths of this had been removed in crops, the remainder was left in the soil. The average annual gain of 120 pounds in the soil nitrogen should probably be credited to the hairy vetch. In this case, the nitrogen in the soil at the beginning, and that added in the seeds and fertilizers was carefully determined as was that in the crops and in the soil at the end of the experiment.

One of the most careful pieces of work on this point was done by Brown and Stallings. These workers grew red clover and alfalfa on two soil types, determining the nitrogen in the soil at the beginning and in the soil and crops as well at the close of the experiment. The total nitrogen in the tops, that in the roots, and the calculated percentage of nitrogen in the tops, was found to vary with the stage of maturity of the plants and the nature of the soil. In many cases, especially at or near blooming time, red clover was found to have taken more nitrogen from the air than was contained in the tops, evidently then some of the nitrogen in the roots also came from the air; this was even more often the case with alfalfa. It was evident that the clover and alfalfa had taken at least three-fourths of their total nitrogen from the air. Lipman and Blair [174] calculated from the data of carefully controlled cylinder experiments that the legumes had taken 54.09 pounds of nitrogen per acre annually from the air.

Thornber [287] found that clover grown in a Montana apple orchard enriched the soil in nitrogen even when the hay was removed. After eight years of clean cultivation, the soil contained 1514 pounds nitrogen per acre; where all the clover had been turned under there were 2019 pounds of nitrogen and where one hay crop had been removed each year there were 2167 pounds. Lipman [172] reports that, on the sandy soil of Lupitz, in Germany, the continued cultivation of lupines for twenty-five to thirty years increased the nitrogen content of the soil about 5000 pounds per acre. During this time, crops were removed and practically no nitrogenous fertilizers were bought. Löhnis [181] has stated that 80 to 100 pounds of nitrogen per acre per year may be expected to be fixed through legumes.

Summing up the Evidence.—Other reports of similar tenor are on record, but enough have been cited to show that legumes vary widely in the amount of nitrogen they take from the air. On fertile soils, this amount will be relatively less than on poor soils and in very rich soils may even approach zero. If a general figure must, for convenience, be used, that first suggested by Hopkins is perhaps as safe as any and we may assume that, under average conditions, and in soil of moderate fertility, a well-noduled legume crop will take about two-thirds of its nitrogen from the air and one-third from the soil. On the other hand some writers have questioned whether legumes really enrich the soil in nitrogen. Swanson studied the nitrogen content of Kansas fields some of which had been many years in alfalfa and others in cultivated crops and compared the results with the nitrogen content of virgin soils in the same neighborhood. He found that, while there was more nitrogen in the alfalfa soil than in that under cultivated crops, there was still more in the virgin soil, which tended to show that the alfalfa can not have taken as much nitrogen from the air as was contained in the crop. Wright grew legumes in galvanized-iron buckets and analyzed the tops and roots. He concluded that when more nitrogen is removed than is taken from the soil this nitrogen will be found in the crop above ground. If this is removed, the soil will have been depleted just as if a non-leguminous crop had been grown and removed.

It is quite evident that, while legumes do undoubtedly draw on the atmosphere for a part of their nitrogen, they do not under natural field conditions ever get all of it in that way. The amount of nitrogen that a given legume will take from the air will vary with a number of conditions, nature of the soil, presence of an abundant supply of phosphorus and potash, luxuriance of growth, age of plants, moisture, temperature, and especially completeness of inoculation. There is also some reason to believe that the nodule-forming bacteria may be of various strains so far as efficiency is concerned. Further, the various legumes differ from each other, some being better nitrogen gatherers than others. It is not possible, therefore, to predict how much nitrogen a given field of legumes will leave in the soil under a given set of conditions, but it will nevertheless be useful to calculate how much nitrogen may be left in the soil in certain cases, as an illustration of what may be expected in others. When the entire crop is turned under for green manure, all the nitrogen is returned and what has been taken from the air is clear gain. But to get a clear picture, the total weight of the crop, roots as well as tops, and the nitrogen content of tops and roots has first to be considered.

Relative Weights of Tops and Roots and Nitrogen Content of Tops and Roots.—The digging out and saving of all the roots of a plant that may send its roots down several feet is a laborious process and, consequently, the data on this subject are not as plentiful as could be desired. Further, owing to differences in soil and methods, the results vary, sometimes widely. This variation is known to be in part due to the fact that legumes vary in nitrogen content with the stage of maturity.

The percentage of nitrogen in tops and in roots may vary not only with the time when the material is taken, but even with the variety. McCool determined the nitrogen in tops and roots of three varieties of alfalfa at different dates. All varieties were grown in the same field at

TABLE XXI

PER CENT NITROGEN IN TOPS AND ROOTS OF ALFALFA SAMPLED AT DIFFERENT DATES, EAST LANSING, MICHIGAN

VARIETY	1924		1925				
	May 21.	June 26.	April 13.	May 21.	June 16.	July 15.	July 28.
	Tops	Tops	Tops	Tops	Tops	Tops	Tops
Grimm	4.09	3.07	6.13	3.55	2.91	5.89	3.97
Cossack	3.92	2.94	5.82	3.57	2.37	5.76	3.56
Common	3.72	2.77	6.07	3.21	2.28	5.56	3.40
	Roots	Roots	Roots	Roots	Roots	Roots	Roots
Grimm	1.73	1.73	2.87	2.11	2.53	2.85	2.54
Cossack		1.54	2.25	1.75	2.02	2.54	2.34
Common	1.70	1.80	2.46	1.59	1.99	2.60	2.16

East Lansing, Michigan. As shown in Table XXI, the percentage of nitrogen in tops was high in April, lower in May and lower still in June, but was more than twice as high in July as in June, only to fall again in August. It is also evident that some varieties may consistently show a higher nitrogen content than others.

Table XXII [1] has been prepared from available data, all secured by workers in the United States, except those for field peas and lupines, which are from Schultz. In studying this table, it should be kept in mind that the figures are approximate and merely illustrative. No two determinations of the ratio of roots to tops or of the nitrogen content ever give exactly the same result. As an illustration of this point, some figures on alfalfa may be cited. Brown and Stallings found that in Carrington loam the roots constituted 40.34 per cent of the total weight, while in Miami fine sandy loam the roots made up 44.87 per cent of the total weight. Alway and Pinckney found that inoculated alfalfa had 37.37 per cent of the total weight in the roots in August, 1907, while in June, 1908, inoculated plants from the same plats had but 21.11 per cent of the total weight in the roots. Arny and Thatcher, in 1914, found 31.43 per cent of the dry weight of alfalfa in the roots, and in 1915, 26 per cent. The average of all these figures is 33.52 per cent, the figure used in Table XXII. The highest figure given above is more than two times the lowest, so it appears that local conditions or age of plants exert great influence on the amount of root growth in proportion to the total weight of the plant. Roots lose less in drying than tops and the percentage of the weight in roots as given for any one lot will vary according as to whether the weights were taken green or dry. Arny and Thatcher give both green and dry weights of alfalfa and, calculated from their figures, the percentage of roots for inoculated alfalfa in 1914 was, green 26.08 per cent, dry 31.43 per cent; in 1915, green 22.8 per cent, dry 26.7 per cent.

A consideration of these facts makes clear how impossible it is to compile a table showing the relative weight of roots and the nitrogen content of various legumes which shall be free from criticisms or perhaps even from error. At best, such a table can be merely illustrative. One generalization may, however, be made, namely, that the biennial and perennial legumes have a larger proportion of the total dry matter and, consequently, a larger amount of nitrogen in the roots than the annual legumes.

[1] Since the purpose in preparing Tables XXII, XXIII and XIV was to bring out the relation between the relative root development of various crops and the nitrogen balance when a hay crop is removed, data were selected that were deemed especially applicable in each case. As far as possible the data for amount of roots and the per cent of nitrogen in tops and roots have been taken from the same work in each case. The object has been not to use a general average as is given in Chapter VI, but to average only those analyses especially applicable to the question at hand.' For example, in the case of sweet clover, analyses of tops and roots and relative weight of roots during late May or June have been used, while analyses for April and early May which would have given considerably higher figures in all columns have been discarded, because sweet clover could not be cut for hay during the early months.

It will be noted that the percentages of nitrogen in tops as given in Table XXII differ from those in Table XXVII, Chapter VI, the latter figures being general averages of all analyses.

TABLE XXII

PERCENTAGE OF ENTIRE CROP IN ROOTS, AND PERCENTAGE OF NITROGEN IN TOPS AND ROOTS, DRY MATTER FOR CERTAIN LEGUMES

	Per Cent Roots of Entire Crop	Nitrogen in Tops Per Cent	Nitrogen in Roots Per Cent
Red clover	33.48	2.70	2.34
Alfalfa	33.52	2.56	2.03
Sweet clover	26.48	2.41	2.04
Crimson clover	24.38	2.85	2.29
Vetch	17.3	3.34	2.16
Cowpeas	14.45	2.70	1.45
Velvet beans	13.2	2.34	1.27
Soybeans	12.18	2.58	1.91
Blue lupines (Schultz	14.6	2.60	1.40
Yellow lupines (Schultz	11.3	2.57	2.17
Field peas (Schultz	4.32	2.8	2.52

It is clear from Table XXII that the clovers and alfalfa have a much larger proportion of their total weight in the roots than the annual legumes, and that the proportion of nitrogen in the roots of the biennials and perennials is also somewhat larger than in the annuals.

Table XXIII gives the calculated weight of roots left in the soil for every ton of hay removed and the calculated amounts of nitrogen left in the soil. It must be again emphasized that these figures are only approximate. Some workers have added stubble to the weight given for roots, while others have not. In general, the figures for nitrogen in the soil, as here given, are too low, as the nitrogen in stubble has not been included in every case. This will vary with the height of the stubble, age, and length of time elapsing before the stubble is plowed.

TABLE XXIII *

CALCULATED DRY WEIGHT OF ROOTS PER TON OF HAY, PERCENTAGE OF NITROGEN IN ROOTS AND POUNDS OF NITROGEN LEFT IN THE SOIL FOR EVERY TON OF HAY REMOVED

	Roots, Pounds	Per Cent Nitrogen in Roots	Nitrogen Pounds in Soil per Ton of Hay Removed
Red clover †	1006.61	2.34	23.55
Alfalfa †	1008.42	2.03	20.47
Sweet clover †	720.35	2.04	14.70
Crimson clover	644.80	2.29	14.77
Vetch	418.38	2.16	9.04
Cowpeas	337.81	1.45	4.90
Velvet beans	304.15	1.27	3.86
Soybeans	277.38	1.91	5.30
Blue lupines	342.00	1.40	4.79
Yellow lupines	255.00	2.17	5.53
Field peas	90.00	2.52	2.27

* The writer is indebted to Mr. E. A. Hollowell for the calculations in Tables XXIII and XXIV.

† One cutting of hay only.

In Table XXIV are given the amounts of nitrogen in one ton of hay and that in the roots for every ton of hay harvested, calculated from Tables XXII and XXIII. Again the nitrogen in the stubble and fallen leaves is not always included. Table XXIV also gives the amount of nitrogen the crop may have taken from the air, based on the assumption that two-thirds of the total nitrogen in the plant has come from the air. It will be noted that, if allowance is made for stubble and fallen leaves, red clover, alfalfa and sweet clover may be expected to leave at least as much nitrogen in the soil as is removed in one hay crop, while crimson clover is not far behind. When a hay crop is taken, annual legumes leave a soil poorer in nitrogen, since the quantity of nitrogen removed in the hay is greater than that which the legumes can be expected to have taken from the air.

Mielck has collected many data from various German workers on the relation between the nitrogen in the roots of legumes and that found in the entire plant. The figures vary so widely that they are not of much practical value, but they do show that, in the case of the annual legumes, lupines, beans, peas, vetches, serradella, the proportion of nitrogen in the roots is seldom as high as 10 per cent or 20 per cent and more often falls between 5 and 8 per cent of that in the entire plant, while for the clovers these figures run from 24 to 74 per cent. From the data in the above tables it will be possible to calculate the approximate quantity of nitrogen that will be returned to the soil when a green manure crop is turned under as well as that actually added to the soil.

TABLE XXIV

POUNDS OF NITROGEN IN ONE TON HAY, AND IN THE ROOTS EQUIVALENT TO EACH TON OF HAY, AND ESTIMATED AMOUNT TAKEN FROM THE AIR

	Pounds in Hay	Pounds in Roots	Total	Pounds Taken from the Air.*
Red clover	54.0	23.55	77.55	51.70
Alfalfa	51.2	20.47	71.67	47.78
Sweet clover	48.2	14.70	62.90	41.93
Crimson clover	57.0	14.77	71.77	47.85
Vetch	66.8	9.04	75.84	53.56
Cowpeas	54.0	4.90	58.90	39.27
Velvet beans	46.8	3.86	50.66	33.77
Soybeans	51.6	5.30	56.90	37.93
Blue lupines	52.0	4.79	56.79	37.86
Yellow lupines	51.4	5.53	56.93	37.95
Field peas	56.0	2.27	58.27	38.85

* Two-thirds of total.

Variations in Nitrogen Content with the Growth of Plants.—The relation between stage of maturity and the amount of organic matter and of nitrogen in a green manure crop is obviously of importance. This is especially so in the case of winter green manure crops and in orchard green manuring. Some time must, of course, elapse between the turning under of the green manure and the planting of the summer crop. In an orchard, it is usually important to get the green manure crop turned under before the soil dries. Naturally, the farm management point of view will be of great, perhaps of prime importance, but it is well to inquire whether there is any loss of nitrogen when the green manure crop is turned under early, and if so, how much.

The first work looking toward an answer to this question was done by Penny [231] in a study of the composition of crimson clover at different stages of growth. Penny studied crimson clover on different fields; on two of these crimson clover had never before been grown, while on one it had been grown for several years. He carried on this study from April 18, when the clover was only 3 to 6 inches high, and merely a mat of leaves on the ground, to the period of full bloom or, in some cases, to some time after full bloom. In every case the greatest total of nitrogen per acre was found at the time of full bloom, but the highest percentage of nitrogen at the beginning of the experiments. It was further shown that the plants on ground that had not before produced crimson clover had, at the beginning of the experiment, but 48 and 65 per cent of the total nitrogen they had at blooming time, while those on land that had frequently borne crimson clover contained 94 and 95 per cent as much total nitrogen in early spring as they did at full bloom. In the first case, early plowing would have involved a distinct sacrifice of nitrogen, in the latter case practically none, Fig. 16.

Brown and Stallings found that the percentage of nitrogen in red clover was greatest at the earliest stage studied, two weeks before blooming. There was, in every case, a slow but steady decrease in the percentage of nitrogen up to maturity, but the greatest gains in total growth and in total nitrogen were made between this early stage and the beginning of bloom. The weight increased then slowly to maturity and the total nitrogen to the period of full bloom or to maturity. Precisely the same course was followed in alfalfa, the young growth containing the highest percentage of nitrogen, but because of the very considerable increase in total dry matter, the plants in full bloom or at maturity had the greatest total nitrogen. It is interesting to note in this connection that, in alfalfa, the increased growth of roots between the early stage and maturity was relatively greater than that of the tops. The reverse was commonly the case with clover.

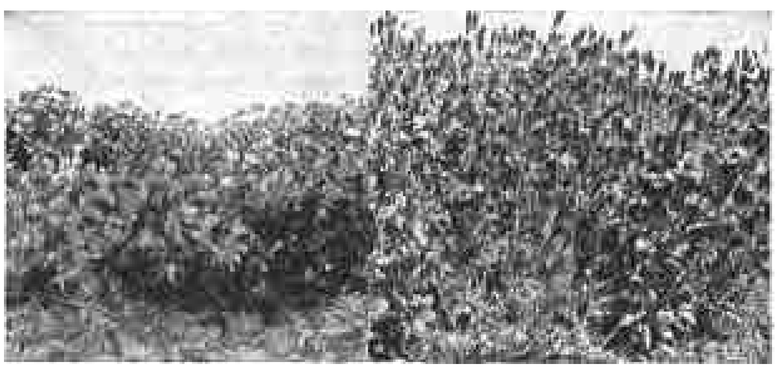

FIG. 16.—At an early stage of growth (left), crimson clover contains the highest percentage of nitrogen; but in full bloom (right), the most nitrogen per acre.
(Photograph by L. W. Kephart.)

Willard has studied the changes in nitrogen content of white sweet clover at different periods of growth. At the end of the first year's growth, September 28, the plants contained as much total nitrogen in tops as they did in the following season, up to the end of April, but between September 28 and April 1, following, the total nitrogen per acre in the roots increased by 80 per cent. The weight of tops increased steadily from April 1 to August 8, of the second season, but the total weight decreased during the same time. The percentage of nitrogen in both tops and roots declined from the end of April to August of the second season, but the total nitrogen per acre was greatest from May 10 to May 31. Whiting and Richmond,[337] in an elaborate study of the nitrogen in tops and roots of sweet clover, also found the greatest total nitrogen in the entire plant early in May. During May the roots constitute more than 50 per cent of the total weight of the plant and contain nearly 50 per cent of the nitrogen, of which 86 per cent is water soluble.

Duggar [55] determined the percentage of nitrogen and the total nitrogen in hairy vetch at different stages of growth from April 19 to May 9. The percentage of nitrogen in both tops and roots fell slowly from just before bloom until pods were formed, but the increase in total weight of dry matter was so great that the total nitrogen was 202.8 pounds per acre on May 9, against 137.0 pounds per acre on April 19.

These studies of crimson clover, red clover, alfalfa, sweet clover and hairy vetch warrant the general conclusion that, at a relatively early stage of growth, the percentage of nitrogen is highest, but that the total nitrogen is greatest at or a little after blooming time, except for sweet clover, in which it is greatest in May some time before coming into bloom. These changes in the relation between the proportion of the plant in top and root, and in the relative proportions of nitrogen, also throw light on the variations in the reported analyses. Unless plants of the same relative ages and growing under the same conditions are analyzed, the results are not comparable.

Effect of Fertilizers on Nitrogen Fixation through Legumes.— That the application of certain fertilizer salts and of lime will increase the yields and also the nitrogen content of legumes is well known, but it is not clear whether the increased nitrogen found was taken from the air or from the soil. Legumes will take nitrates from the soil as readily as they will nitrogen from the air and an increased nitrogen content is not always evidence that this nitrogen has been fixed through the nodule bacteria. The efforts to determine what effect various salts have on nitrogen fixation through legumes have therefore been mainly directed to a study of the effect which these salts have on the nodule bacteria and on the formation of nodules. Among the most recent students of this problem may be mentioned Fred and Graul,[73] Hills, MacTaggart, Fellers, and Wilson, all of whom have reviewed the literature.

Lime and phosphorus have generally been found to increase the number and size of nodules, except that for serradella lime is injurious not only to the plant but also to the formation of nodules. In the case of lupines lime is beneficial on soil of pH value 4.9 to 5.05 but may be harmful on less acid soil. Nitrates, on the other hand, were found to prevent the development of nodules when the nitrates were present in any but low concentrations. Hills showed that, while concentrations of 100 to 500 parts of nitrate to 1,000,000 of dry soil stimulated reproduction of *B. radicicola* so that the number of organisms increased greatly, higher concentrations caused a decrease in the number of organisms. Nodule formation was injuriously affected at a concentration of 100 parts and completely prevented at 250 parts per million. The injurious effect of nitrates in moderate concentrations on nodule formation is evidently not due to toxic action on the organisms, since these multiply and, when removed to soil free from nitrates, produce normal nodule formation. All experiments show, however, that nitrates in concentrations of 100 parts or more per million of dry soil depress or wholly prevent the formation of nodules.[1]

[1] Since the preparation of this manuscript, Bulletin 436 of the New Jersey Agricultural Experiment Station has appeared containing a paper by Gunnar Giöbel entitled: The Relation of Soil Nitrogen to Nodule Development and Fixation of Nitrogen by Certain Legumes. Giöbel found that while in the early stages of growth a good supply of combined nitrogen was beneficial, the amounts of atmospheric nitrogen fixed by established plants were in all cases, "inversely proportional to the amounts of soluble nitrogen at the disposal of the plants." The student is referred to Giöbel's paper for a full discussion and literature.

Sulphur has been found to stimulate nodule formation on clover and alfalfa in some cases, but Wilson found that sulphates depressed nodule formation in soybeans. It is clear that calcium and phosphorus are beneficial while nitrates are harmful to nodule production, but it may be added that except in highly manured soils the accumulation of nitrates does not often reach the concentrations used in the experiments reported.

Nitrogen Fixation in Leaves.—An interesting case of the symbiosis of nitrogen fixing bacteria and certain tropical plants has been described by von Faber. He found rod-shaped bacteria living in the leaves of certain species of *Rubiaceae,* and fixing nitrogen, which was evidently used by the plants. When plants free from bacteria were cultivated in nitrogen-free sand, they showed every sign of nitrogen hunger, while plants with bacteria under the same conditions soon recovered healthy growth and became green, showing that they were getting nitrogen. Adinaryana Rao [see footnote previous page] has recently shown a similar relationship between bacteria and certain tropical plants in India. It seems probable that other cases will be found.

Non-Symbiotic Nitrogen Fixation.—Besides the fixation of nitrogen by the bacteria that live in the legume nodules, it is known that a certain, though apparently not large, amount of nitrogen is fixed by free living bacteria in the soil. A number of species have been found to fix atmospheric nitrogen when cultivated under the proper conditions, but the most important are *Clostridium Pastorianum,* which is active only in the absence of free oxygen, and *Azotobacter,* a large aerobic organism of which several species have been described. The forms of *Azotobacter* are widespread, but appear to thrive only on neutral or alkaline soil. They are not found in acid soils, but when these soils are limed, they often appear. The legume nodule bacteria have also been said to be capable of fixing atmospheric nitrogen outside of the roots of legumes, but later workers have failed to confirm this. All these free living forms require a supply of energy material and for this they utilize the carbon of organic matter in the soil. The decomposition of cellulose as well as the sugars in the decaying plants provide *Azotobacter* with the necessary energy material and enable it, and other microörganisms, to fix an appreciable amount of free nitrogen. Phosphates and potash are also necessary.

Amount of Nitrogen Fixed by Azotobacter Types.—The fixation of nitrogen by these forms has been studied mostly in laboratory experiments and there is little exact information in regard to their efficiency in the soil. At the Rothamsted station it was found that at least 25 pounds of nitrogen per acre per year had been added to a field in which no leguminous crops were growing. Most of this was presumably fixed by free living microörganisms. The Illinois Agricultural Experiment Station found that *Azotobacter* fixes 15 pounds of nitrogen, while using the carbonaceous material in 1212 pounds of fresh clover tops, or in 5500 pounds of corn stover. Dvorak arrived at about the same figure for clover; other workers have also found that the turning under of green manure crops increased the non-symbiotic nitrogen fixation in the soil. It is generally believed that some readily available carbohydrate will enable *Azotobacter* to fix the maximum quantity of nitrogen, but Lipman and Teakle reported a greater fixation in a soil from which all readily soluble carbon had been removed than is commonly reported as being fixed in sugar solutions. Fulmer [77] found that nitrogen was fixed after fresh green wheat and clover had been worked into the soil, the greatest gain in nitrogen occurring two weeks after the green manure was added and amounting sometimes to 60-100 pounds of nitrogen fixed for 30,000 pounds green manure turned under.

Dvorak found that the older the plant material becomes, the poorer it is as a source of energy for *Azotobacter.* The roots and residues of rye and maize were only about one-sixth to one-half as efficient as red clover. Löhnis [181] estimates. that free living bacteria may store in their bodies 10 to 40 or more pounds of nitrogen per acre per year. There is no doubt that these organisms may be made a valuable source of nitrogen, provided they are well supplied with suitable energy material. Winogradski, one of the greatest authorities on soil organisms, insists, however, that nothing is actually known about the amount of work *Azotobacter* does in the soil. In the present state of our knowledge it is perhaps idle to speculate on how much nitrogen is fixed by *Azotobacter,* but we can be sure that this and similar organisms do add more or less to the nitrogen content of many soils.

Attempts have been made to prepare cultures of *Azotobacter* for the purpose of enriching the soil with efficient organisms. Several preparations have been put on the market, but thus far these have proved of no value.

The Addition or the Transformation of Nitrogen.—It is important to keep in mind that, in the course of the biological activities in soils, there may be both a transformation and an addition of nitrogen; in fact these processes are doubtless going on together all the time when moisture and temperature are favorable. The transformation of nitrogen adds nothing to the soil and may, indeed, withdraw considerable quantities of available nitrogen from crop plants, while the addition of nitrogen should sooner or later benefit crop plants.

All microörganisms need energy material and nitrogen, and most of them will seize upon the most available source for their nitrogen. In doing this, the nitrogen is transformed from organic nitrogen, from ammonia, or from nitrates into protein nitrogen fixed in the bodies of the soil fungi or bacteria. When a substance, as straw, containing much energy material and little nitrogen, is turned into the soil, the microörganisms may so completely deplete the soil of nitrates as to result in nitrogen starvation for the crop. Later, on the death and decay of these microörganisms, the nitrogen in their bodies again becomes available, but not necessarily to crop plants. A new generation of microörganisms may use it for the formation of protein in their own bodies; and the cycle of nitrogen transformation may begin anew.

When non-leguminous green manure crops are turned into the soil, no nitrogen is added, the inorganic nitrogen formerly present in the soil has merely been transformed into organic nitrogen. When these plants decay, the organic nitrogen is again transformed into inorganic nitrogen and the cycle is complete. Nitrogen is added to the soil only when legumes, which contain more nitrogen than they have removed from the soil, are turned under, when ammonia is carried down by rain, when stable manure or nitrogenous fertilizers are added, or when nitrogen is fixed by free living microörganisms.

The Nitrogen Cycle.—The nitrogen of the soil has its origin in the gaseous nitrogen of the air and sooner or later, by one route or another, most of it returns to the air. Figure 17 illustrates graphically how the nitrogen may pass from the air to the microörganism, to the legume, to the animal, and back to the soil to become nitrate nitrogen and so to feed the crop plants.

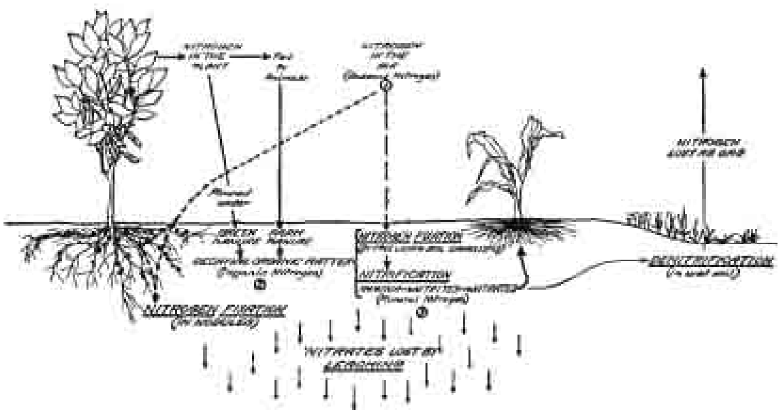

FIG. 17.—The Nitrogen Cycle. Diagram illustrating the transformation of nitrogen. (U. S. Department of Agriculture.)

Availability of Green Manure Nitrogen.—It is well known that all the nitrogen in a green manure crop is not recovered in the crops grown after it. A crop of sweet clover that would make a ton and a half of hay early in May would return to or add to the soil about 100 pounds of nitrogen, equal to more than 600 pounds of nitrate of soda. A 60-bushel crop of corn will remove in grain and stalks 90 pounds nitrogen and a 40-bushel crop of wheat in grain and straw, 80 pounds. If all the nitrogen in the legume became available, there would seem to be more than enough nitrogen in the sweet clover to supply either the corn or the wheat, but such complete utilization does not occur. Many studies with widely varying results have been made to determine just how much of the green manure nitrogen is used by a subsequent crop. In general, it is known that the nitrogen in green manures is more completely available than that in stable manure, but less completely than that in nitrate of soda.

Various German students have been concerned to determine the relative availability of the nitrogen in green manures, in stable manure, and in nitrate of soda. But here again the results vary so widely that only very general averages can be struck and, as applied to specific cases, these mean little.

Wagner [305] found that, as an average of two years' tests, the relative value of nitrate of soda, green manure, and stable manure was:

Nitrate of soda	100
Green manure	77
Stable manure	26

In a later publication,[307] however, he changed the figures to:

Nitrate of soda.	100
Green manure...	70
Stable manure	45

Schneidewind and associates [247] turned under various legume green manures and grew beets, oats, potatoes, and barley, and figured the percentage of the green manure nitrogen utilized by the crop following:

Total nitrogen utilized by beets and by the oats following the beets:	Per Cent
From beans, peas and vetches, mixed	24.6
From *Medicago lupulina*	25.4
By beets and barley following the beets:	
From *Medicago lupulina*	54.8
From alsike clover	52.7
By potatoes and barley following potatoes:	
From *Medicago lupulina*	54.1
By oats:	
From *Medicago lupulina*	41.2
From beans, peas and vetches, mixed	17.7

In a later publication Schneidewind and associates [248] determined the increase in oats per unit of nitrogen in nitrate of soda, black medic and in a mixture of peas, beans and vetches, as follows:

	Loam	Sand
Yield from 4 grams nitrogen in nitrate of soda	100	100
Yield from 4 grams nitrogen in black media	70.1	73.4
Yield from 4 grams nitrogen in mixed legumes	50.8	71.4

The percentages of nitrogen utilized by oats and a following crop of buckwheat grown in loam and in sand are given as follows:

	Loam, Per Cent	Sand, Per Cent
Out of 4 grams nitrogen in nitrate of soda	75.8	75.5
Out of 4 grams nitrogen in black medic	40.8	36.5
Out of 4 grams nitrogen in mixed legumes	30.5	33.5

In another test, the results from nitrate of soda were compared with those from the total green manure crop produced and turned down. The increased yields of oats were:

	In loam, Grams	In sand, Grams
From nitrate of soda equal to 400 kg. per Hectare	39.0	28.7
From a crop of black medic	53.0	38.6
From a crop of mixed legumes	17.6	21.1

Maercker grew various green manuring plants and, when in bloom, mixed the finely cut tops with loamy sand in such amounts that each lot contained the same quantity of nitrogen. In 1895, white mustard was grown, and in 1896, oats followed by white mustard. The results for those legumes that were used both years are given below. The nitrogen recovery from nitrate of soda is placed at 100.

	1895	1896
Nitrogen recovered from nitrate of soda	100.0	100.0
Nitrogen recovered from *Lathyrus Wagneri.*	61.9	86.7
Nitrogen recovered from Lucerne	53.5	26.6
Nitrogen recovered from red clover	38.9	31.1
Nitrogen recovered from esparcette	16.1	80.3

The esparcette used in 1895 was old and Maercker points out that the action of the green manures that year was in direct proportion to the amide content of the green manure material. The great variation in the results secured makes it at once evident that no exact measure of the value of the nitrogen in green manures can be arrived at in this way, if indeed in any way. Differences in age and in leafiness of the material as well as in the proportions of the more readily soluble nitrogen compounds present, will have marked effects. This is one of the many subjects connected with green manuring that needs more thorough study.

Lipman and Blair [176] studied this question by means of cylinder experiments and found that the green manures grown between main crops had yielded more nitrogen to the harvested crops than 160 pounds nitrate of soda per acre annually or 15 tons of manure every two years. In another paper,[174] these authors rate the value of nitrate of soda, green manures and stable manure in the ratio 100 ; 65 : 25. The amounts of dry matter and nitrogen recovered in crops by Lipman and Blair, following various treatments including green manure are illustrated graphically in Fig. 18. Mooers, in a study of the nitrogen recovered by wheat from a cowpea green manure crop, concluded that while 63.4 per cent of the nitrogen in stable manure was recovered in the crop, only 42.5 per cent of the nitrogen in the cowpeas was recovered. These results differ radically from those secured by most workers and may be of local rather than of general application. Löhnis states that the nitrogen availability of legume green manures may vary between 16 and 86 per cent, generally 50 per cent, while the availability of stable manure is most frequently about 25 per

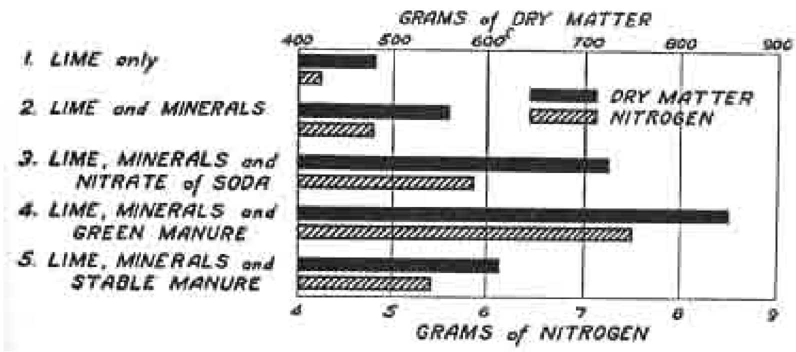

Fig. 18.—More dry matter and nitrogen were secured by the use of green manures than by any other treatment.

1, Lime only; 2, lime and minerals; 3, lime, minerals and nitrate of soda; 4, lime, minerals and green manure; 5, lime, minerals and stable manure. (Drawn by L. W. Kephart from data in N. J. Agr. Expt. Sta. Bul. 289.)

cent. This author further points out that the availability of green manure nitrogen will depend upon (1), quality and quantity of the green manure turned under: (2), the time it is turned under and the character of the soil; (3), the kind of crop that follows. Naturally if a quickly decomposing crop like cowpeas is turned under during warm weather and some time before the following crop is able to use the nitrates, there will be much loss and a correspondingly low recovery.

Under the intense heat of the tropics the nitrogen in green manures becomes available rapidly, Hutchinson and Milligan finding 50 to 60 per cent of the nitrogen in green manures nitrified in eight weeks.

Adinaryana Rao [2] studied three tropical legumes and found that in eight weeks 25.83, 38.33, and 53.33 per cent of the nitrogen in each of the legumes studied was made available as ammonia or as nitrate. In the, same period the availability of nitrogen in various oil cakes ranged from 57 to 80 per cent.

The availability of the nitrogen in any substance that must needs undergo as many transformations in the soil as green manures before the nitrogen becomes available to crop plants, must depend on many factors, soil, moisture, temperature, nature and abundance of the microflora, loss by leaching, which, in turn, will depend on the time the green manure is plowed in and the nature of the following season. Any exact and comprehensive statement is, therefore, impossible. No figures that might be selected would be likely to apply to any specific case and, as was the case when the amount of nitrogen fixed was under consideration, it is necessary to fall back on some arbitrary approximation. As such an approximation, the figures suggested by Lipman and Blair will, perhaps, do as well as any and, as a convenient measure, it may be said that the relative value of the nitrogen in nitrate of soda, green manures, and stable manure is probably as 100 to 65 to 25. During the first year after turning under, about 40-45 per cent of the nitrogen in green manures may be expected to become available.

SUMMARY

Excluding atmospheric precipitation and the application of stable manure and artificial fertilizers, nitrogen is added to the soil only through the activities of microörganisms. Functionally, these are of two kinds, symbiotic and non-symbiotic; among the former those of agricultural value are commonly associated with the roots of legumes and the latter are free living in the soil.

The amount of nitrogen fixed through legumes is variable in quantity, but it seems reasonable to conclude from the evidence at hand that on the average about two-thirds of the nitrogen in the entire legume plant is derived from the air. When the relative weights of tops and roots of legumes are examined, it appears that only in a relatively few cases is as much nitrogen taken from the air as is contained in the hay and, if this is removed, the soil will be depleted of nitrogen to a greater or less extent.

Non-symbiotic nitrogen fixation goes on constantly in all neutral or alkaline soils, but to a less extent in acid soils. The amount of nitrogen thus added to soils has been estimated at from 10 to 25 pounds per acre per year. Free living nitrogen fixers need a supply of energy material and the organic matter of green manure crops has been found to be an especially good source of energy for these organisms.

The transformation of nitrogen is not an addition of nitrogen. When non-legumes are turned under, the nitrogen they previously took from the soil is merely transformed from organic to nitrate nitrogen. In the course of these transformations, nitrogen may be locked up in the bodies of microörganisms and may be made temporarily unavailable to crop plants.

Not all of the nitrogen in green manures becomes available to the succeeding crop. It is not possible to determine just how much does become available, as this varies within wide limits, but in general the availability of the nitrogen in nitrate of soda, in green manures, and in stable manure, is believed to be in the ratio of 100 to 65 to 25.

CHAPTER VI

CHEMICAL COMPOSITION OF GREEN MANURE PLANTS

MANY analyses have been made of agricultural plants and it would be impossible as well as profitless to summarize all of these. The dry matter of plants consists of carbon, nitrogen, hydrogen, oxygen, phosphorus, potassium, sodium, calcium, magnesium, iron, sulphur, chlorine, and silica, as well as of other constituents present in smaller amounts. Of these hydrogen, oxygen, carbon and nitrogen are driven off by burning and the remaining elements constitute the ash. In the analyses of plants from the standpoint of soil fertility, nitrogen, phosphorus, potassium and less often calcium and sulphur, are determined.

Composition Affected by Conditions.—It is well known that different species of plants growing together under the same conditions vary widely in the percentages of the various elements they contain. Plants of different groups are sometimes characterized by their high content of certain elements; thus the legumes generally contain more nitrogen than the grasses, and tobacco, rape and turnips are especially rich in potash. In the case of legumes this increased nitrogen content is directly connected with the presence of nodule bacteria, but, in the case of plants with a consistently high content of certain mineral elements, it can only be said that this is a characteristic of the plant.

On the other hand, plants are affected by the conditions under which they grow. Jost quotes older writers as giving the lime content of plants growing on calcareous soil as 45 per cent of the ash, while the same species growing on sand had only 30 per cent of lime in the ash. In general, plants growing on soils with abundant available minerals will have a higher ash content than those growing on soils poorly supplied with available minerals. Seiden found that rye grown in loam contained a higher percentage of ash than when grown in sand or in a humus-rich soil.

The nitrogen content may also be affected by the soil conditions. The variation in nitrogen content of legumes at different stages of growth has already been mentioned, p. 76. In legumes, the nitrogen content also depends to a large extent upon completeness of inoculation. White [326] made a study of red clover and sorrel on the plats of the Pennsylvania Agricultural Experiment Station. A summary of many analyses prepared from Tables VIII and IX of these studies is given in Table XXV.

It will be noted that each plant took more calcium from the alkaline soil than from the acid, but less magnesium, while in both cases most silicon and potassium were taken from the acid soil.

Neller found that the application of sulphur to certain soils in Washington increased the nitrogen content of clover and alfalfa, in some cases between 20 and 40 per cent; in other cases, there was no increase or sometimes even a slight decrease. When the sulphur effected an increase in yield, this was usually accompanied by an increase in the percentage of nitrogen; similar results have been reported by other workers. In studies on Idaho soils,[216] it was found that applications of sulphur increased the sulphur in the ash and also increased the nitrogen content of the plants; application of phosphorus also resulted in an increased sulphur content and in most cases in an increased nitrogen content of the plants. In a study of the effect of different crops on the lime and other chemical constituents of the soil and this effect on the following crop, Burgess, in Rhode Island, showed that "where either phosphorus or potassium had been withheld in fertilization, larger percentages of iron and aluminum were usually found in all of the tissues analyzed. Where potassium was omitted, larger quantities of magnesium, calcium, phosphorus, and silicon were absorbed, the magnesium content of the leaves especially being increased. A lack of nitrogen, while retarding growth, has little effect on the percentage composition of the plants, although a slight tendency to reduce calcium and magnesium absorption was indicated in the leaves." Price also found that the application of lime and phosphorus enabled alfalfa to absorb larger quantities of these elements. This was especially evident in the first cutting.

TABLE XXV

COMPOSITION OF RED CLOVER AND SORREL ON ACID, NEUTRAL AND ALKALINE SOIL

(Percentages on Basis of Dry Matter)

Soil	Silicon	Manganese	Calcium	Magnesium	Phosphorus	Potassium	Nitrogen
Red Clover							
Composite No. 1 Alkaline	1.734	0.0741	3.02	0.234	0.174	0.924	2.63
Composite No. 2 Neutral	1.681	0.0592	2.68	0.414	0.182	0.851	2.70
Composite No. 3 Acid	1.931	0.0851	2.67	0.344	0.144	1.021	2.46
Sorrel							
Composite No. 1 Alkaline	1.54	0.122	2.91	0.325	0.200	1.94	1.27
Composite No. 2 Neutral	1.74	0.108	2.66	0.456	0.221	1.88	1.24
Composite No. 3 Acid	2.45	0.153	2.04	0.386	0.310	2.15	1.25

In a study of spinach diseases, True, Black and Kelly found that, when spinach plants growing in the field were treated with sodium sulphate, the potassium content of both roots and stems was high, while on the other hand, an application of acid phosphate resulted in a decreased absorption of potassium. It has been claimed by German writers that the chemical composition of plants can be used as an index of the availability of certain elements in the soil. While this is not generally accepted, it seems probable from all the evidence that the plant's content of nitrogen and minerals depends to some extent upon the availability of the elements in the coil on which the plants grow. To what extent plants may take variable amounts of minerals from fertile soils in which all elements are present and available in ample quantities is not known with sufficient accuracy. Similar accuracy is lacking in our knowledge on the effect that the physical condition of the soil or climatic conditions may have on the chemical composition of plants. The ash content of a plant and the proportions of the various elements in the ash may vary with the time of the year when the samples are taken. Thus Seiden [251] found that in a cherry tree the proportion of ash in the plant increased from May to September, but the percentage of potash and phosphoric acid in the ash decreased, while that of calcium and silicon increased during this time.

A study of the many analyses of plants does, however, show that species vary in their composition, sometimes to a considerable extent. As an illustration of this fact, a study of various legumes by Jones and Bullis,

TABLE XXVI

POUNDS OF FIBER AND OF FERTILIZING CONSTITUENTS IN 1000 POUNDS OF DRIED ROUGHAGE OF SOME PLANTS

Species	Fiber	Nitrogen	Phosphoric	Potash
Kentucky blue grass	660	13.3	5.4	21.0
Millet, Common Hungarian	680	13.3	3.6	21.5
Red top	610	11.8	4.4	18.8
Timothy, all analyses	500	9.9	3.1	13.6
" before bloom		15.7		
" early to full bloom		10.1		
" late bloom to early seed		8.8		
" nearly ripe		8.3		
" rowen		23.0		
Rye, all analyses		10.7	5.0	17.0
" heading out to in bloom		15.7		
" 4 to 6 inches high *a*	161.**7**	39.76		
Alfalfa, all analyses	430	23.8	5.4	22.3
" before bloom		35.2		
" in bloom	430	24.0		
" in seed		19.5		
Beggar weed		24.6	9.4	27.9
Clover, Alsike, all analyses	480	20.5	7.0	17.4
" " in bloom		21.1		
" bur	640	30.7		
" crimson	470	22.6	6.1	22.4
" berseem		23.0	6.3	24.7
" mammoth		17.3	6.3	8.7
" red, all analyses	540	20.5	3.9	16.3
" " before bloom		29.9	7.4	22.1
" " in bloom	530	21.0	5.7	15.4
" " after bloom		18.6	4.0	11.0
" rowen	470	26.4		
" white sweet	340	23.2	6.6	12.6
" yellow sweet		21.4		
" white dutch		25.9	5.2	20.0
Cowpea, all analyses	470	30.9	9.6	41.3
" before bloom		41.9		
" in bloom to early pod		20.6		
" ripe		16.2		
Field pea (Canada		24.2	6.7	12.4
Peanut vine, mowed	520	15.5		
Serradella	500	25.1	10.3	15.1
Soy bean hay	570	25.6	6.8	23.3
Trefoil or black medic		27.0	5.7	8.1
Velvet bean		26.2	5.5	26.5
Vetch, common	570	27.7	7.9	18.6
" hairy	590	31.8	10.3	26.2
Rape		30.2	12.6	46.8
" 12 to 14 inches high *a*	158.4	36.86		
" 18 to 20 inches high *a*	170.2	41.0		
Buckwheat *f*		25.4	14.26	52.5
Cow horn turnip roots *d*		18.2	9.2	32.5
" " " .. tops *e*		25.1	5.6	31.3
Mustard, white *f*		40.0	11.4	28.6
Mexican clover				
(Richardsonia scabra) *g*	234	2	11.2	
Lathyrus clymeneum tops *b*		31.1		
" " roots *b*		25.7		
Lupine, white, tops *b*		25. 0		
" " roots *b*		17.7		
" yellow, tops *b*		25.7		
" " roots *b*		21.7		
" blue, tops *b*		26. 0		
" " roots *b*		14.0		
Lathyrus tingitanus (Green weight) *c*		4.92		
Vicia atropurpurea (Green weight) *c*		5. 69		
Lentils (Green weight) *c*		6.50		
Fenugreek (Green weight) *c*		5. 57		
Melilotus indica (Green weight) *c*		5. 56		
Lespedeza striata *h*		21.7		
Lespedeza stipulacea *h*		26.5		

a Iowa Bul. No. 136. *b* Schultz. *c* Cal. Bul. 292. *d* Aver. Mass., N. J. and Del. analyses. *e* Delaware analysis. *f* Wollny.[347] *g* Florida Quarterly Bul. 26. *h* Bur. Chemistry, U. S. D. A.

in western Oregon, may be cited. All samples were carefully hand-gathered at about the same stage of maturity. The air-dried samples of red clover varied in nitrogen content in the extreme cases by 0.47 per cent and the common vetch by 0.888 per cent. For this reason, isolated analyses are of limited value and even averages of many analyses must be accepted with a certain reserve, as it is not always possible to know whether all samples represented were of the same age and had beenproduced under comparable conditions. As a rule, young plants **or** plant parts will be richer in potash and phosphoric acid and poorer in lime than old plants or plant parts. There is no doubt, however, that the average of many analyses represents the general trend of composition of the given plants.

Average Composition of Plants.—The most complete collection of data on chemical analyses of plants is to be found in Henry and Morrison. These are averages from United States Experiment Station data, and hence, probably represent as fair averages as can be had. As such, they are not directly applicable to any specific case, but represent what may be expected. In Table XXVI below, a number of analyses of green manuring plants are given, together with a few analyses of other common forage crops for comparison. Except as indicated these are all taken from Henry and Morrison.

It will be noted at once that the legumes contain less fiber and more nitrogen than the grasses, but that rape is unusually high in all fertilizer constituents and that cow-horn turnips are high in potash. It must be remembered, however, that rape has taken all of its nitrogen from the soil; hence when these crops are turned under no net increase of nitrogen results.

Composition of Some Tropical Legumes.—Cover crops and green manures are of importance in the tropics, not only to protect the soil, but to furnish the nitrogen so easily lost in regions with heavy rainfall, hence some of the more important analyses available have been brought together in Table XXVII. Those starred are from Thompson, the others from Koch.[158]

Composition of Some Weeds.—Weeds often have a value as green manure for they contain nitrogen and minerals, though, since weeds are rarely legumes, the nitrogen has been taken from the soil. The following table gives analyses of a few weeds, some of which may occasionally serve as late summer cover and green-manure crops. Weeds commonly die at the first heavy frost, so they do not often serve as conservers of nitrogen in late fall and early spring. Only the more common weeds have been selected for this table.

It is at once evident from Table XXVIII that weeds may contain considerable quantities of fertilizer elements, all of which should be conserved by turning the weeds under rather than allowing them to be dispersed by wind and weather.

TABLE XXVII

PERCENTAGE OF NITROGEN AND PHOSPHORIC ACID (P_2O_5) IN DRY MATTER OF SOME TROPICAL GREEN-MANURE PLANTS

	Age in Days	Nitrogen				Phosphoric Acid	
		Roots, Per Cent	Above Ground, Per Cent	Total Per Cent	Pounds per Acre	Total Per Cent	Pounds per Acre
Crotalaria usaramoensis	901		4.55	4.55	74.54	0.516	8.39
" "	135			2.04	174.71	0.255	21.90
" "	138			2.07	214.31	0.246	25.47
" "	154			2.56	250.03	0.479	46.75
" "	190			1.57	201.89	0.208	26.71
" anagyroides	75			2.31	74.54	0.470	15.22
" "	90			1.86	104.83	0.570	32.07
" "	107			1.97	159.18	0.396	31.99
" "	122			1.86	197.23	0.352	37.27
" "	134			1.70	197.23	0.385	44.73
" "	135			1.50	153.75	0.278	28.50
" "	138			1.16	158.41	0.248	33.86
" "	153			0.93	130.45	0.215	30.13
" "	154			2.00	312.15	0.413	62.97
* " juncea		1.31	2.64	2.18			
* " incana		1.76	2.90	2.51			
* " saltiana		1.90	3.22	2.84			
* Canavalia ensiformis (Jack bean with pods		1.44	2.69	2.21			
Cassia mimosoides	134			1.29	119.58	0.508	47.13
" chamaecrista		1.52	2.41				
Centrosoma Plumieri	196			2.41	61.34	0.782	19.80
Desmodium gyroides	185			1.58	52.80	0.339	11.34
* " uncinatum—Spanish clover		1.62	2.75				
* Dolichos biflorus (Kulthi		2.33	2.87				
Indigofera hirsute	148			1.94	168.50	0.287	24.85
" sumatrana	148			1.10	96.29	0.266	23.22
" "	354			1.04	297.40	0.155	44.49
* " anil		2.04	2.64	2.43			
Mimosa invisa	135			3.19	115.70	0.522	18.95
" "	176			3.09	106.38	0.801	27.57
* " pudica (Sensitive plant)		0.81	1.04	0.91			
Phaseolus semicrectus	135			1.76	111.04	0.341	21.59
* " "		1.80	2.84	2.51			
* " mungo (Mung bean		1.67	2.53	2.29			
" lunatus	176			3.08	133.56	0.805	34.94
* Sesbania aegyptica		1.28	1.30	1.22			
* Stizolobium pachylobium—(Velvet bean		1.63	2.17	2.00			
* Stizolobium deeringianum—(Florida velvet bean		1.66	2.32	2.16			
* Stizolobium nivium (Lyon bean		1.74	2.31	2.24			
* " aterrinum—(Mauritius bean		1.81	2.15	2.08			
Tephrona Vogelii	154			1.64	100.17	0.306	18.71
" "	349			1.33	239.94	0.235	42.24
" Candida	196			1.80	135.11	0.592	44.42
" Hookeriana	354			1.64	194.13	0.237	28.03

* Thompson: others Koch [158]. † Prunings.

TABLE XXVIII
PERCENTAGE OF NITROGEN, PHOSPHORIC ACID, POTASH, AND CALCIUM IN SOME WEEDS

	Nitrogen	Phos-phoric Acid	Potash	Lime
(1) Achillea millefolium (Yarrow)	1.71	0.5	2.98	
(2) Achillea millefolium (Yarrow)	2.30	0.93	3.15	3.84
(3) Amaranthus retroflexus (pigweed)	4.246			
(1) Ambrosia artemisiaefolia (ragweed)	1.36	0.41	1.79	
(1) Andropogon scoparius (broom sedge)	0.78	0.21	0.68	
(1) Aster lateriflorus (stickweed)	1.92	0.56	1.61	
(3) Brassica (common mustard)	2.52			
(1) Carduus arvense (Canada thistle)	2.06	0.45	2.74	
(4) Carduus arvense (Canada thistle)	3.36	0.89	5.48	5.30
(2) Centaurea cyanus (corn flower)	2.30	0.78	1.94	3.13
(4) Chenopodium album (lamb's quarters)	3.99	1.33	10.91	3.61
(3) Chenopodium album (lamb's quarters)	4.00			
(1) Chrysanthemum leucanthemum (Ox-eye daisy)	2.12	0.46	2.88	
(4) Convolvulus arvensis (morning glory)	3.62	0.94	4.91	1.87
(1) Daucus carota (wild carrot)	1.65	0.62	4.21	
(1) Lactuca canadensis (wild lettuce)	1.07	0.47	2.20	
(1) Linaria vulgaris (toad flax)	1.83	0.64	2.30	
(3) Malva rotundifolia (mallow)	4.00			
(2) Polygonum persicaria (lady's thumb)	3.12	1.16	3.12	4.93
(3) Portulaca oleracea (purslane)	4.18			
(2) Raphanus raphanistrum (wild radish)	1.85	0.78	1.30	1.81
(1) Rumex acetosella (sorrel)	1.38	0.21	1.89	
(1) Setaria glauca (foxtail grass)	1.77	0.75	4.52	
(1) Solidago juncea (golden rod)	1.27	0.39	1.62	
(3) Solidago sp. (golden rod)	1.86			
(4) Sonchus oleraceus (sow thistle)	3.19	1.12	7.82	2.92
(2) Sonchus oleraceus (sow thistle)	2.39	0.88	4.77	1.94
(4) Stellaria media (chickweed)	3.85	1.69	10.93	1.99
(1) Digitaria sanguinalis (crab grass)	1.89	0.90	4.67	
(3) Taraxicum offieinale (dandelion)	2.83			

(1) Millspaugh. (3) Snyder [270].
(2) Stutzer and Seidler. (4) Kling.

* Nomenclature according to Gray's "Manual of Botany", Seventh Edition.

SUMMARY

While all plants contain nitrogen, phosphoric acid, and potash the relative proportions of these elements vary in different plants. These proportions are affected by the age of the plants and to some extent by the conditions under which they have been grown as well as by the fertilizers applied.

The average composition of most plants used for green manuring has been given as well as the composition of some weeds. Weeds may contain large percentages of fertilizer elements and should be turned under, rather than wasted.

CHAPTER VII

DECOMPOSITION OF GREEN MANURES

"THE biochemical decomposition of plant residues and other organic matter in the soil is of fundamental importance for soil fertility. It causes the breaking down of coarse plant fragments which otherwise might open up the soil too much: it leads to the production of colloidal complexes known as humus, which exert many beneficial effects both chemical and physical, and it brings about the formation of nitrates, the most important of the nitrogenous plant nutrients."[243]

Decomposition of organic matter is a necessary preliminary to utilization, since the protein molecule must be broken down before crop plants can use the minerals and the nitrogen which are locked up in the plant cell. The work of breaking down is done by bacteria and fungi of many kinds and takes place in several stages, various intermediate products being formed before the final substance, nitrate, useful to crop plants, appears. While earthworms and various insects help to break down organic matter by subjecting portions to the action of digestion, no estimate of the degree of such help can be made. At any rate such action can go no further than to make such matter more readily available to microörganisms.

Decomposition may be aerobic or anaerobic, proceeding in the former with access of free oxygen and in the latter in the absence of free oxygen. Anaerobic decomposition has been called putrefaction. With the exception of green manures used in rice fields, most of the decomposition of plant material used for green manuring proceeds aerobically and the following discussion refers to this form of decay. A brief discussion of anaerobic decomposition is given on p. 108.

Knowledge of What Goes on in the Soil Incomplete.—There is as yet little known about what happens in the soil. Many phases of decomposition have been studied in the laboratory, but events as they follow one another in the soil are but dimly understood. It is known that organic matter is attacked by microörganisms; that carbon dioxide and ammonia are formed, that the latter, or part of it, eventually becomes transformed into nitrate; that, in the course of decomposition, various intermediate compounds are produced and substances are synthesized by microörganisms; and that some of these intermediate products may be assimilated by crop plants, while others are poisonous. Most of this information has been obtained through laboratory studies and it is an open question whether all the conclusions are applicable to field conditions. While it has been shown that some of the chemical changes going on in the soil can take place under the influence of catalysts, these changes have not been produced under conditions such as obtain in nature. On the other hand, these changes are known to be brought about by bacteria and fungi under conditions of temperature and moisture like those that exist in the field, and hence it is believed that the breaking down of organic matter and the later production of nitrates from ammonia are exclusively the work of the microörganisms. Russell [242] has represented diagrammatically some of the changes that occur in decomposition, though many of the intermediate

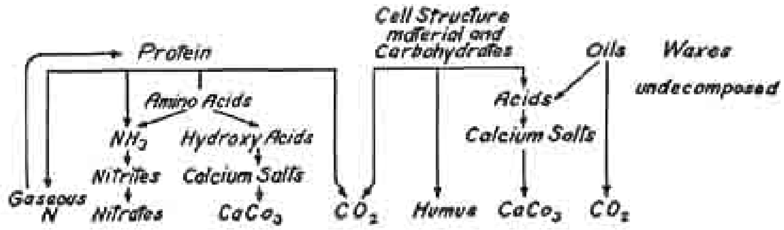

FIG. 19.—Diagram illustrating the principal chemical changes during decomposition. (Redrawn with modifications by L. W. Kephart, from Russell, Soil Conditions and Plant Growth, Longmans, Green & Co., New York, 1915.)

products are not shown in the diagram, Fig. 19. It will be noted that carbon dioxide (CO_2) is one of the end products of the decay of both protein and carbohydrate material, while nitrate is derived from protein only.[1]

A General View of What Goes on in the Soil.—In spite of our ignorance of details, a general picture of what is going on in the soil can be drawn and it will be useful for the student to get such a picture clearly in mind. Under suitable conditions of moisture and temperature, millions of organisms of many different kinds are active in every cubic centimeter of fertile soil. Every species and individual may be affected by the activities of some or of all the others. Chemical reactions, such as between acids and bases take place and physical forces, surface tensions, adsorption phenomena and others are operative. Toxic substances may be formed and slow up the reactions of some organism, only to be removed by another or by an excess of soil moisture; the amounts of oxygen and of carbon dioxide in the soil air may change and so affect the well-being of the microörganisms and finally the crop growing on the land may also influence the course of events. As soon as a fresh mass of plant material is turned under, the biological activities receive a great impetus. They, in turn, affect chemical changes and these may react on the minerals in the soil. All the activities normally going on in the soil are speeded up and new ones develop.

About all the scientist can do to-day is to measure some of the end products, each the result of the interaction of many organisms and of chemical and physical forces. What may be called the last act of the drama can be seen, but of the forces that work toward this end there is as yet little definite knowledge.

Rapid and Slow Decomposition.—The more readily decomposable parts of green manures, as leaves and tender stems, are first attacked and the nitrogen quite rapidly converted into nitrates. The result is that a short time after the plant material is turned under, ammonia and nitrates are formed for immediate consumption. The more resistant parts decompose more slowly, the nitrogen in part becoming available later in the season, while the mixture of decomposition products and more resistant material goes to make up the humus of the soil. As far as nitrogen is concerned,

[1] The diagram (Fig. 19), has been slightly modified from that in the 1915 edition of "Soil Conditions and Plant Growth," in accordance with suggestions from Dr. Russell. His view is "that the nitrogen in the humus is in the form of protein (or some similar compound) closely combined with the humus, but not an integral part of the humus molecule." According to Waksman [316] the substance that has commonly been called "humus" is largely lignin in nature but the nitrogen content has not been accounted for, though he suggests that it may be derived from the synthesizing activities of soil miroörganisms. The student is urged to consult Waksman's paper.

two possibilities exist, the rapid production of nitrates for the growing crop, and the more gradual increase in the nitrogen content of the soil. Green manuring must, therefore, be considered from two points of view: the supply of nitrates for the immediately following crop, and the increase in soil organic matter to improve tilth and to supply nitrogen for the use of future crops. This fact has led some to distinguish between active and inactive organic matter, the former decaying quickly and producing nitrates early, the latter being attached with difficulty so that the nitrogen is but slowly changed to nitrates.

Methods of Measuring the Rate of Decomposition.—As with ammonification and nitrification, the work done on the rate of decay of plant material and the influences of various substances on decomposition has mostly been done in the laboratory. Under such conditions, the aeration, moisture and temperature can readily be maintained at the optimum. Due allowance must, therefore, be made when applying the conclusions to field conditions where the above-mentioned factors are variable and not always optimum. The results do, however, indicate the various forces at work in the field.

The evolution of carbon dioxide has been used more than any other as a measure for the decay of organic matter and it is without doubt the best measure available. All plant material contains carbon and the loss of that as carbon dioxide shows that decay is taking place. The production of ammonia and the accumulation of nitrates have also been used to measure decomposition, but of necessity can not be as good measures of decay as the evolution of carbon dioxide, since purely carbohydrate materials, as sugars and cellulose, will not produce ammonia or nitrates. On the other hand, the accumulation of nitrates measures more accurately the value to crops of the decomposition of organic matter.

Attention must again be called to the fact that the nitrates accumulated represent merely the *surplus* between production, on the one hand, and consumption and loss on the other. The microörganisms that bring about decay, themselves require nitrogen, and, being ever on hand, they are certain to get what nitrogen they need out of any organic nitrogen, ammonia, or nitrates available to them. What is not needed by the microflora or is not lost from the soil remains as accumulated nitrate. Under a growing crop, this too takes its share. When an excess of carbohydrate material, as straw, is placed in the ground, the microflora may even consume the nitrates previously in the soil and, for a time, cause reduction rather than accumulation of nitrates.

That the amount of carbon dioxide evolved in decay does not necessarily agree with the accumulation of nitrates is shown in the work of Holtz and Singleton. They determined the carbon dioxide evolved and the nitrates accumulated in forty-four days from the decay of alfalfa and sweet clover. The following data are taken from Table IV of their paper:

	CO_2, Mgs. in 44 Days	Nitrate Nitrogen, P.p.m. in 44 Days
Virgin soil	111.7	13.8
Virgin soil + alfalfa	628.1	18.0
Virgin soil + sweet clover	632.5	38.3
Cropped soil	116.5	13.4
Cropped soil + alfalfa	691.3	26.4
Cropped soil + sweet clover	700.7	37.1

The amount of humus formed has been suggested as a measure of decomposition, but has not proven of value.

Objections to These Methods.—Measuring the decomposition of organic matter by the evolution of carbon dioxide has been criticized on the ground that some of the carbon dioxide may be absorbed by the soil and that some may be consumed by microörganisms. This objection is valid and it may be added that, where the experiments are conducted in soils carrying a crop, the roots themselves may add to the carbon dioxide of the soil air. If lime is present, this may absorb part of the carbon dioxide produced and a part may be dissolved in the soil solution. In any case, the rate of decay is probably greater than that shown by the carbon dioxide secured. Some of these objections apply with even greater force to the use of ammonification and of nitrate accumulation as measures of decay. Part of the ammonia produced may be absorbed by the soil and it is quite certain that more of the ammonia than of the carbon dioxide will be used by the microörganisms.

Nitrate accumulation is subject to various factors. In control pot tests without a growing crop and no leaching there may still be a loss, because some nitrate is used by microörganisms and the wide variation often found in duplicates as by Maynard shows that the formation of nitrates is not always uniform, even under apparently uniform conditions, or that the methods used are far from exact.

Conditions that Affect Decomposition.—The rapidity as well as the completeness of decomposition is controlled by many factors, moisture, temperature, aeration, soil texture, presence of lime and mineral salts, age, condition, and character of material turned under, and the presence of suitable organisms.

Moisture.—Moisture is necessary; in a bone-dry soil, decomposition does not take place or only slowly. In a saturated soil, decomposition is replaced by putrefaction. Hutchinson and Milligan buried very young plants and determined the carbon dioxide evolved. They found that, after eight weeks in air-dry soil, 10.8 per cent of the organic matter had decomposed; at 12 per cent moisture, 59.4 per cent; at 18 per cent moisture, 67.8 per cent; at 24 per cent moisture, 52.2 per cent; in saturated soil (48 per cent) there was no evolution of carbon dioxide. The optimum moisture was 18 per cent. Sandy, clay or loam, and peat soils differ in their water-holding capacity—but, in general, 60 to 80 per cent of the water-holding capacity of a soil is said to be the optimum for decomposition. Wollny[348] found that decomposition of organic matter increased with increasing moisture and temperature. Jodidi [136] found a close relation between the rainfall in Iowa and the amount of carbon dioxide in the soil air, this being greater during periods of abundant than during periods of light precipitation. Potter and Snyder [233] also found that rainfall had a decided influence in increasing the carbon dioxide in the soil atmosphere, but believe with Russell and Appleyard that this is partly due to the dissolved oxygen in the rainwater. In regions of low rainfall, the lack of moisture becomes the limiting factor in the decay of a green-manure crop. In one case a crop of barley about 2 feet high was turned under in California in early May with the expectation that rains would follow. No rain followed, however, and, though the soil was moist when plowing was done, crops on that field failed and when the ground was next plowed a layer of undecomposed plant material was found. There had not been moisture enough for complete decay, and the layer of rye had effectively cut off the upward movement of the soil water. See also Ammonification and Nitrification, pp. 51 and 52.

Temperature.—Soil microörganisms are active through a rather wide range of temperatures, but a rise in temperature speeds up their action and, consequently, hastens decomposition. Wollny [348] found the optimum temperature for the evolution of carbon dioxide to be 35° C. and the maximum temperature between 65 and 80° C. Jodidi [136] found that, when the precipitation was about the same during two months, April and June, the higher temperature during June caused an increase in the carbon dioxide of the soil air. Paganiban found that ammonification was active up to 60° C.

Green manures turned under in fall decay more slowly than those turned under in spring and, when freezing weather follows soon after plowing in fall, there is probably little or no loss of nitrogen. Whiting and Richmond [336] determined the nitrates present in soil on which sweet clover was fall plowed and spring plowed. On November 25, the difference in nitrate content between the soil of the check plots and of those on which sweet clover was growing was small. Some of these sweet-clover plots were fall plowed, and nitrate determinations made on May 5 following showed no greater accumulation of nitrates on the fall-plowed sweet clover than on the check plot. As measured by nitrate formation, little decomposition had taken place in the fall-plowed sweet clover ground.

Aëration.—The decomposition that results in the formation of nitrates is aerobic. The nitrifying organisms are active only in the presence of an abundant supply of oxygen. In a saturated soil, the anaerobic organisms cause the breaking down of organic matter, resulting in the formation of various gases. (See p. 109.)

Russell and Appleyard made a careful study of the relation between the carbon dioxide in soil air, the accumulation of nitrates, temperature, moisture, rainfall and bacterial numbers. The results were plotted and the conclusion reached that carbon-dioxide production, nitrate content, and bacterial numbers are related phenomena and that they are influenced by temperature, moisture and rainfall. The temperature factor was found to be operative chiefly in spring, when with rising temperature there was also a rapid rise in the production of carbon dioxide. Later, although the temperature continued to rise, the production of carbon dioxide fell and, through the summer, was more closely related to moisture and especially rainfall. The special effect of rainfall is believed to be related to the large amount of oxygen carried into the soil by the rain.

Climate, Soil Type and Fertility.—Decomposition goes on more rapidly in light soils than in heavy ones, and in fertile than in poor soils. In the first case this is doubtless an aeration effect, a more constant and abundant supply of oxygen being present in sandy than in clay soils. It is notoriously difficult to keep up the organic matter in sands, it soon "burns out" while in heavy soils, especially if these are also wet, decay proceeds slowly. Wollny found that decomposition was more rapid in cultivated than in virgin soils and this fact has also been brought out by Holtz and Singleton for soils in the Yakima Valley of Washington. Starkey, while noting that decomposition was most rapid in fertile soils, found no striking difference in the rate of decomposition in different soils. In a warm, humid climate decay proceeds more rapidly than in one that is cold and humid or warm and dry. The soils of the wet tropics are poor in organic matter, not because a luxuriant vegetation is lacking, but because decay proceeds rapidly and constantly. In the northern United States decay largely ceases with the advent of winter and is not resumed till spring, but in the southern states decay goes on most of the time, though not so actively in winter as in summer. The long hot summer of the southern states tends to a rapid destruction of organic matter, especially on the light soils of the coastal plains. These facts have an important bearing on the use of green manures, on the time of turning under and on the kind of crop to follow the turning under of a green-manure crop.

The effects of climate, soil type and fertility are all to be referred to the influence of temperature, moisture, aëration, and food supply on the activities of the soil microörganisms. These are more active at higher temperatures and in the presence of plenty of oxygen decomposition more rapidly goes to completion than where an excess of moisture or a very heavy soil prevents aeration. The effect of tillage too is of the same nature, since this tends to increase the ease with which air gets to all parts and to maintain a desirable degree of moisture in the upper layers of the soil.

Effect of Lime and Minerals.—The presence of lime has been found to favor decomposition. Some writers indeed hold the contrary view, but the weight of evidence appears to show that lime favors the development of microörganisms and the evolution of carbon dioxide. Kellner and associates [145] found that slaked lime favored the decomposition of organic matter, but more in dry soils than in wet ones, the loss from the former being nearly three times as great as from the latter.

As to the action of fertilizers, results are conflicting. While phosphates, no doubt, act to hasten decay, various workers have found no increased decomposition in the presence of potash, Merkle finding even a slight decrease in the carbon dioxide evolved when soybean fodder was mixed with soil plus potash salts. Sulphate of ammonia appears to hasten decomposition, at least at first, and the work of Hutchinson and Richards has shown clearly that plant materials poor in nitrogen, as straw, can be rapidly decomposed if the bacteria (and fungi?) are supplied with a source of nitrogen. Wollny[348] found that mineral acids in every case decreased the rate of carbon dioxide evolution from soils, while weak alkaline salts increased it. Stronger solutions, however, had the opposite effect and had this in proportion to the increased concentration of the salts.

It may not be out of place here to call attention again to the fact that decomposition and all associated phenomena, as ammonification and nitrification, are the results of biological activity. The organisms concerned, bacteria or fungi, require nitrogen and the mineral elements as well as carbon. The effect of these substances on decay will be in proportion to the need for them by the soil microflora.

Effect of Stable Manure.—The addition of small amounts of stable manure to green manure has long been known to be good practice. Very large numbers of bacteria, some of them efficient cellulose decomposers, are added to the soil in the manure and besides this the manure, especially if well rotted, provides a readily available supply of nitrogen for the immediate use of the microflora and thus tends to increase the growth and activity of those forms that attack the carbonaceous material. In this way decay is hastened.

Age of Plant Material.—As they grow older, plants contain smaller percentages of nitrogen and larger percentages of carbon. The carbon is also present in a more resistant form, cellulose and lignin increase and the plant becomes hard and woody. Such older material decomposes more slowly than young material. Bal showed that, as measured by the carbon dioxide evolved from *Crotalaria juncea,* there was a regular fall in the rate of decomposition as the plant material advanced in age. A study of the nitrate production further showed that a much higher percentage of nitrogen in young plants was nitrified than of that in older plants. While 56.26 per cent of the nitrogen in *Crotalaria juncea* two weeks old was nitrified in two weeks, 36.73 per cent of that present in plants four weeks old, 24.09 per cent of that in plants six weeks old, and 1.06 per cent of that in plants twelve weeks old was nitrified in the same time. In the entire incubation period of ten weeks, the older plant material did not produce the same proportion of nitrates as the younger material. Martin found that young rye, oats and buckwheat decomposed more rapidly than older material. The most satisfactory stage was when the crops were about half-grown. At this stage they gave the largest returns in the subsequent crop. Hartwell and Pember [106] found that oats turned under before heading had a better effect on the following spinach crop than when turned under in the milk stage.

Wright [350] found that green rye and green vetch turned under caused the production of considerable quantities of nitrates in one month, while straw caused a decrease in the quantity of nitrate accumulated, and concluded from this that the use of green manures that had been allowed to become mature or nearly so was unwise. It is doubtful, however, whether the results with straw can be carried over to old green-manure plants, especially legumes. Hutchinson and Milligan found that, under like conditions, 67.8 per cent of the nitrogen in plants of *Crotalaria* four weeks old was nitrified in eight weeks, while in the same time only 50 per cent of the nitrogen in plants six weeks old and 34.5 per cent of that in plants ten weeks old was nitrified.

There is good ground for assuming that young, fresh material will decay more rapidly than old, but some experienced farmers prefer to plow under the material after maturity, insisting that better results are secured by this practice. So far as known, however, in these cases, the material is turned under in fall and there is time for the preliminary stages of decay to be passed before the need of rapid nitrate formation. German writers advocate turning under lupines late or leaving the dead plants on the ground till early spring, so that the first stages of decay will take place above ground. It is quite evident that young, fresh material should not be plowed under during summer, unless a crop is to be seeded soon, as favorable conditions at that time will cause rapid decay and nitrification with consequent loss of nitrate by leaching. On the other hand, a woody growth, like mature sweet clover, should not be turned under shortly before a crop is seeded, as the slow decay will delay the formation of nitrates or may even reduce the amount in the soil. Young sweet clover as in Fig. 20 should be turned under in spring for a rapidly growing crop like corn, while mature sweet clover, Fig. 21, should be turned under in fall for a spring-planted crop. In this case the early stages of decomposition will be passed in fall and in early spring.

Effect of Composition, Dryness, and Character of Material.—The decomposition of plant material is greatly influenced by its composition. Materials high in nitrogen decompose more readily than those high in carbon and low in nitrogen. Wollny [348] found that various legume straws produced more carbon dioxide than grain straws. However, the decomposition of straw and of other material high in carbohydrates proceeds rapidly, provided a supply of available nitrogen is present for the use of microörganisms. The simpler carbohydrates are more readily attacked by microörganisms than the higher forms, as celluloses, and for this reason, among others, young plant material, which is usually rich in sugar, is more readily decayed than the older material. The state of division is of some importance also. Dried ground material decomposes

Fig. 20.—The time to turn under will vary with the maturity of the green-manure crop. Young sweet clover should be turned under in spring for a crop of corn, potatoes or beets. (Photograph by L. W. Kephart.)

readily, since it is quickly moistened and presents a large surface to the action of the microörganisms. Some of the conclusions published to the effect that dry material decomposes as readily as fresh, appear to be due to this factor. Lemmerman and associates [170] concluded that lucerne hay decomposed as readily as fresh lucerne, but in their experiments the fresh material was first dried and both kinds were ground finely before mixing with the soil.

Whiting and Shoonover found that, when red clover with some brown heads was dried in a breeze for three days and compared with fresh material, both lots mixed with soil, the production of nitrates proceeded

FIG. 21.—Mature sweet clover should be turned under in fall for the next year's hoed crop. (U. S. Department of Agriculture.)

more rapidly with the fresh than with the dried material. Leaves decay more readily than stems. Bal studied the relative rate of decomposition in leaves and stems of *Crotalaria* by mixing ten grams leaves and 10 grams of top, middle and bottom stems with 200 grams soil in each case. After four weeks, the percentage of the nitrogen that had been nitrified was, for leaves, 36.88, top stems, 44.66; middle stems, 21.97; and bottom stems, none. In this case the failure of the nitrogen in the bottom portions of the stems to be nitrified was due, not to a lower percentage of nitrogen, but to increased fiber, rendering the material more difficult of attack than the younger material. The lower portions of the stems actually contained more nitrogen than the upper.

Joshi[141] found that, in every one of six leguminous green-manure crops studied, the nitrogen in the leaves nitrified more rapidly than that in the stems or in the roots. One of his graphs is reproduced in Fig. 22 and shows that, for *Crotalaria,* the nitrogen in stems and roots became

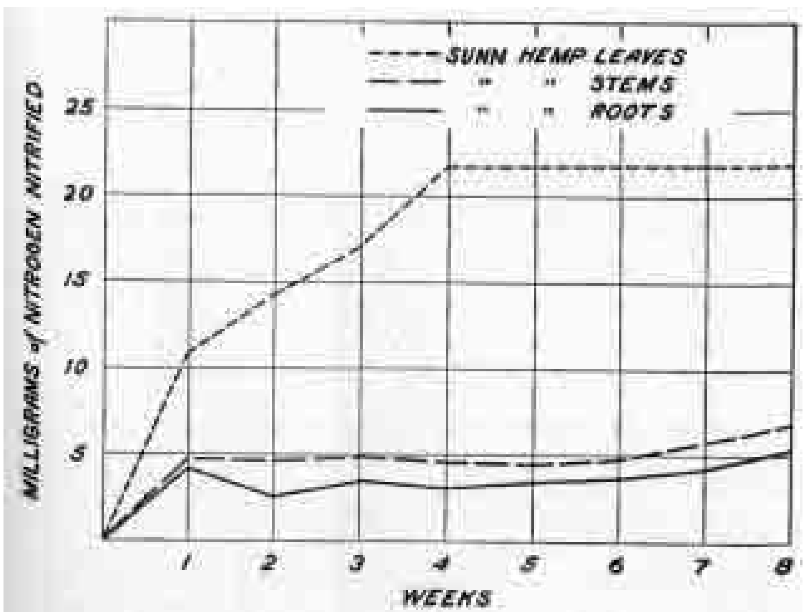

FIG. 22.—The nitrogen in leaves becomes nitrified more rapidly than that in stems or roots. (Redrawn by L. W. Kephart from Joshi, Agricultural Journal of India, 14, 1919.)

available in about the same degree, while that in the leaves nitrified more readily. In this experiment, portions of leaves, stems, and roots containing equal amounts of nitrogen were separately mixed with the soil.

Joshi found also that there was a material difference in the completeness with which the nitrogen in the leaves of various plants became available, but it is not clear whether this is due to a difference in rate of decomposition or to some factor more directly connected with nitrification only. In a later paper, Joshi [142] showed that, when oats were grown after whole legume plants, leaves, stems, and roots had been separately mixed with soil, the oats grown after legume leaves had been turned under, invariably produced the larger crop. In some cases, the stems or roots alone of the legume turned under even caused a decrease in crop.

Lemmerman and Tazenko found a relation between the fiber content of plants and the readiness with which the nitrogen in these plants became available. Their data are given in Table XXIX.

TABLE XXIX

PERCENTAGE OF NITROGEN MADE AVAILABLE AND FIBER CONTENT OF FIVE PLANTS USED AS GREEN MANURE

	Nitrogen Made Available, Per Cent	Fiber Content, Per Cent
Lupines	2.26	33.80
Rape	3.62	34.57
Beans	6.26	30.85
Serradella	13.29	20.13
Vetch	17.54	23.80

These authors further referred the slower rate at which the nitrogen of lupines became available to the greater lignin content of these plants which is evident from the following data:

	Crude Fiber, Per Cent	Cellulose, Per Cent	Kutin, Per Cent	Lignin, Per Cent
Lupines	33.8	11.53	4.59	17.68
Serradella	20.13	11.36	3.74	5.03

Anaerobic Decomposition.—This type of decomposition has been called putrefaction to distinguish it from decay or the decomposition taking place with access of air. The two types run together, since a soil may at one time be in a condition which favors aerobic and at another time in a condition which favors anaerobic organisms. There are also organisms that can thrive either with or without free oxygen. These are known as facultative aerobes or anaerobes. However, under conditions of complete submergence as when organic matter is puddle into rice fields and the fields are flooded, aerobic decomposition is excluded. Under these conditions, nitrates are quickly denitrified and decomposition proceeds more slowly than when the soil is aerated. Jeannert, as quoted by Voorhees and Lipman, found that with the exclusion of air "decomposition is considerably less rapid, and complete decomposition requires, with the exclusion of air, a period of time six times as long." While a great deal of work has been done on the course of anaerobic decomposition, there is yet little exact knowledge of the products formed and their importance in plant nutrition. Ammonia is said to be one of the products of the breaking down of the protein molecule, though Wollny [348] states that only small amounts of ammonia are produced. Kelley,[144] however, found "active ammonification in completely saturated soils." Various secondary nitrogenous compounds as Leucin, from which ammonia may be formed and which Schreiner and Skinner found could be utilized by plants, are produced as well as various poisonous substances. "The coincident presence furthermore, of the carbohydrate-splitting bacteria and of denitrifying microörganism renders the actual process of putrefaction a chaos of many activities in which the end-products and by-products are qualitatively determinable with much inexactitude, and which completely defies any attempt at quantitative analysis."[115] The gases produced as a result of the anaerobic decomposition of plant material have been studied by Onodera and by Harrison and Subramania Aiyer.[100] The gases produced were found to be chiefly Methane, Carbon dioxide and Nitrogen with smaller amounts of Hydrogen and Oxygen. Harrison and Subramania Aiyer suggest that the ammonia and some of the nitrogenous decomposition products may be utilized by the rice plants. In a later paper [101] these authors express the view that in swamp-rice soils the organic nitrogen is given off as nitrogen gas and is, therefore, of no use to the rice. The benefit derived from the decomposition of the plant material is, therefore, indirect and is exerted by the oxygen which, dissolved in the water, serves to aerate the roots. This oxygen was found to be not a product of decomposition, but of the life processes of a film of microörganisms, diatoms and algae, growing on the surface of the water and which utilized the carbon dioxide given off by the putrefying material and in turn gave off oxygen. This, dissolving in the water, was carried by slow drainage to the roots of the plants.

If the theory put forward by these workers is correct, the green manuring of rice serves a very different purpose from that served by the green manures turned under for crops not grown under swamp conditions. The end result in both cases, however, is an increased crop.

How Soon after Green Manure is Turned under Does Decomposition and Nitrate Accumulation Begin?—Under favorable conditions of moisture and temperature, plant material turned under begins to decay immediately. Holtz and Singleton showed that, when alfalfa or sweet clover was mixed with soil, there was a large evolution of carbon dioxide in two days, showing the prompt beginning of decay. Potter and Snyder[234] found a considerable increase in the carbon dioxide evolved the first day after turning under oats and clover at the rate of 1 ton air-dry material per acre in each case.

Starkey found that, after two days, 35 per cent of the carbon in dextrose, 26 per cent of that in alfalfa, 19 per cent of that in fungus mycelium, 16 per cent of that in rice straw, 7 per cent of that in dried blood, and 0.5 per cent of that in cellulose was eliminated as carbon dioxide. In most cases, where such experiments have been made, the carbon dioxide was not measured each day, but Joshi [141] found that nitrate accumulation from young Sesbania began almost at once, was considerable in one week, and nearly doubled in two weeks. Merkle found a large evolution of carbon dioxide in two weeks and a considerable nitrate accumulation in 44 days, and Bal found that 56.26 per cent of the nitrogen in young green material was nitrified in two weeks. Stephenson found vigorous nitrification two weeks after alfalfa was turned under. Whiting and Richmond [335] determined the nitrates present under growing corn. On the plots receiving sweet clover as green manure, vigorous nitrification was found going on within a month and sometimes within two weeks from the time of plowing.

It is evident that decomposition of young green material begins as soon as the plants are turned under. The microörganisms attack the succulent tissues and the formation of nitrates for crop use follows in a few days or weeks. In the case of very succulent material, the greater part of the nitrate may be produced in the first eight weeks, and it is important that a growing crop be ready to use this nitrate.

Decomposition as Related to Bacterial Numbers.—Since decomposition is a biological phenomenon, it is to be expected that the microflora of the soil will increase during decomposition of green manures. The addition of such material largely increases the food supply and, hence, the number of all microörganisms using that food will increase. This is not only true of bacteria, but also of fungi and the recorded increases in bacterial numbers give but one part of the picture. Although the relative amount of decomposition, affected by fungi and by bacteria has not been established definitely, it is known that fungi play an important part in decomposition and that their numbers increase with the available food supply. The progress of decomposition has been found in some cases to be marked by fluctuations and the number of bacteria to coincide roughly with these fluctuations.

Briscoe and Harned found that the numbers of bacteria increased after turning under young oats or alfalfa, that these increases were much greater when lime also was added and that the increases were most marked during the early stages of decomposition. As the more readily available food is consumed, the bacterial numbers decline. Engberding, who has studied exhaustively the factors affecting bacterial activities in the soil, found a 400 per cent increase in bacterial numbers after adding straw to a soil and a still greater increase after adding mustard and vetch. Not only are the numbers of bacteria increased, but Waksman and Starkey [320] also found an increase in the numbers of soil fungi present after adding straw and alfalfa meal. They give the following figures:

INCREASE IN THE NUMBERS OF FUNNGI AND OF BACTERIA AND ACTINOMYCETES 14 DAYS AFTER ADDING STRAW AND ALFALFA MEAL TO SOIL *

Soil	Fungi	Bacteria and Actinomycetes
Untreated	38,700	8,875,000
Soil + straw	136,000	34,200,000
Soil + alfalfa meal	297,000	74,600,000

* From Soil Science 17: 375. By permission of the Williams and Wilkins Co., Baltimore.

Figures of this sort, however, are only illustrative. Under conditions even slightly different other numbers would probably be secured. When some readily available carbohydrate, as sugar, has been added to soils, the numbers of bacteria have increased enormously.

Carbon Dioxide as a Fertilizer.—Since carbon dioxide is one of the chief products of decomposition and since it is the source of all plant carbon compounds, it is of interest to note that the carbon dioxide of decomposition may be turned to account by crop plants. While carbon dioxide is not a fertilizer in the commonly accepted sense, it has been thought that an increase in the amount of this gas in the atmosphere about plants would enable them to produce more sugar and starch, grow more rapidly and so yield larger crops. The atmosphere contains only 0.03 per cent carbon dioxide, and from this small amount green plants must get all their carbon transforming the carbon dioxide under the energy of the sun into the various carbohydrates. Many experiments have been performed to test this point. In some cases carbon dioxide gas has been led through perforated pipes into beds of vegetables under glass and increased yields have been reported. In other cases, especially in field trials where large quantities of green manures and of stable manures have been turned under with the idea that the large amounts of carbon dioxide evolved during decay would stimulate growth, no positive results were secured. Gerlach and Seidel tested a commercial product designed to serve as a carbon dioxide fertilizer. This was found to contain soluble nitrogen, phosphoric acid and potash, and when like quantities of these fertilizers were added to the control beds, no increases were secured from the carbon dioxide fertilizer.

The entire subject has lately been reviewed by Niklas, Scharrer and Strobel who show that, in some cases, a crop increase could be demonstrated as a result of increasing the percentage of carbon dioxide in the air, but in other cases no increase could be shown. This matter needs further study before definite conclusions can be reached.

Does the Decomposition of Green Manure Increase Soil "Acidity"? —There are still some gaps in our knowledge of soil acidity and this is not the place for a review of the subject. It is enough to say that there is a soil condition unfavorable to many crop plants and especially to such legumes as red clover and alfalfa; this condition can be corrected by the application of lime, and is known as "acidity." The degree of this "acidity" can be stated in terms of lime requirement and also in terms of hydrogen-ion concentration. Several methods for determining the lime requirement of soils have been proposed and certain of these give results widely different from others. It has been thought that the decay of green manures, especially in large quantities, tended to the formation of acid decomposition products and thus to an increase of acidity. The investigations on this point are not many, but those made point to the conclusion that no serious degree of soil "acidity" is to be feared from turning under green manure.

In 1914, White [328, 330] studied this question on the soil of the general fertilizer series of plats at the Pennsylvania State College. The soil of these plats had become very "acid" and, by the Veitch method,[1] showed a lime requirement of more than two tons calcium carbonate per acre 7 inches. To this soil, in one series, a number of green manures, legumes, and non-legumes, were added fresh in amounts equal to 20 tons dry matter per acre 7 inches; in another series, the green manures were added dry. The mixtures were then exposed in jars under conditions favorable to decay and lime requirement determinations were made at intervals during nine months.

At the end of two weeks, the lime requirement in all the green-manured soils was very greatly reduced, in the case of red clover from 4644 pounds for the check to 713 pounds. This decrease in lime requirement continued for the legumes during three months, but later the time requirment rose and at the end of nine months it was slightly higher than the check. The non-legumes also showed an initial lowering of the lime requirement, but this did not last as long as in the case of legumes, and from three months to the end of the test the lime requirement in the non-legume green-manured soils remained higher than the check. The net result in this case was to leave the green-manured soil at the end of nine months with a somewhat higher lime requirement than the check soil.

In connection with an extensive study of lime and lime requirement of soils made by Ames and Schollenberger, these authors also studied the effect of turning under legume and non-legume green manures on the lime requirement of soil. The soil used had but a low lime requirement and 8000 pounds of dry green manurial matter or the equivalent in fresh material was added to the soil. At the end of three months the lime requirement had been reduced by all the green manures, both dry and fresh

[1] The Veitch method is one of the standard laboratory methods of determining how far "the soil's absorptive powers for calcium must be satisfied before a distinctly alkaline extract can be obtained." Ames and Schollenberger describe the operation as follows: "A number of 10-gram samples of the soil to be tested are treated with different quantities of standard lime water, evaporated to dryness, taken up with 100 cubic centimeters of water and allowed to stand over night in a small flask. Half the clear liquid is drawn off and boiled to a small volume with a drop of phenolphthalein indicator. The lime requirement of the soil in question is taken to correspond to the minimum quantity of lime water necessary to give an alkaline reaction to the extract." The student should consult the above-mentioned authors for a discussion of various methods of determining lime requirement and a review of the important literature.

and, at the end of fourteen months, the lime requirement for all green-manured soils, though higher than at three months, was still lower than that for the check. The green manures added dry had lowered the lime requirement more than when added fresh. A second experiment gave similar results, except that green soybean hay increased the lime requirement.

Hill studied the effect of green manuring on soil acidity, using five different Virginia soils and both legumes and non-legumes. In pot tests, the green manures increased the lime requirement slightly, but Hill adds that in field trials "the turning under of green crops has not materially increased the lime requirement of the soil, but has, in a large number of cases, reduced the lime requirement."

Howard [128] concluded from a study of certain plats at the Rhode Island Agricultural Experiment Station that "there is no evidence that any acidity has resulted from the use of rye as a cover crop for a quarter of a century. The legumes (mainly vetch) however, have during the same time considerably increased the lime requirements." In a laboratory study, on the other hand, this author found that rye "increased the lime requirement 300 to 400 pounds, or about twice as much as clover."

Miller,[205] in certain field trials found that the untreated soil increased slightly in acidity during the early part of the season and decreased later" Wheat straw and horse manure turned under decreased acidity for the first eight weeks, after which the acidity gradually increased to about that of the untreated plots at the end of twenty-six weeks. The same results were secured for green oats, dry oats, green clover and dry clover, although not in so striking degree. Green sorghum turned under markedly increased the acidity of the soil for the first eight weeks when a rapid decrease took place for six weeks. The acidity dropped almost to the level of the untreated soil. Dry sorghum turned under showed a less striking increase in acidity for the first eight weeks. In this case the acidity dropped to exactly the acidity of the untreated soil during the next six weeks. In general, these experiments indicate that the ordinary green manures turned under either dry or fresh do not increase soil acidity, although a crop containing much sugar, as in the case of sorghum, does appreciably increase soil acidity for a few weeks. This acidity later decreases."

It will be noted that, in the experiments reported above, the final lime requirement of the soil was increased only in pot tests, except that on the Rhode Island soil the vetch increased the soil acidity, while the rye did not. In the experiment conducted by White, non-legumes increased the soil acidity more than legumes. It is possible that some other factor besides the decomposition of the vetch was operative on the Rhode Island plats. The quantities of green manure used by White, 20,000 pounds of dry matter, are several times greater than the quantities that would be used in practice. The field trials reported, except those from Rhode Island in part, show no increased acidity due to green manures. The results of experimental work on the "acidity" produced by green manures are somewhat conflicting, but on the whole, they tend to show that green manures do not increase soil "acidity" or, if so, that such a condition is transitory. When properly turned under, there is probably little danger that the quantities of green manure likely to be plowed under on farms in the United States will exert any lasting effect in increasing the lime requirement of soils.

Effect of Decomposition on the Germination of Seed.—It has been found that some seeds planted soon after a green-manure crop has been turned under may be injuriously affected and the germination be poor or fail altogether. Fred [69] studied the effect of green manures on the germination of various seeds, as cotton, soybeans, flax, hemp, mustard, peanuts, clover, corn, and oats. He found that, when cotton was planted immediately after a green-manure crop was turned under, germination was prevented or seriously retarded, depending on the quantity of green manure turned under. Soybeans were also very sensitive, while corn and oats were not injured. As a rule, oil seeds were readily damaged, while starchy seeds were not. Figure 23 shows the effect on the germination of cotton seed when planted as soon as the green manures were mixed with the soil. Pots A and B had no green manure; C and D had green manure at the rate of 2500 pounds per acre; E and F, at 5000 pounds; G and H, at 10,000 pounds; and I and J, at 20,000 pounds. The seeds in the upper row were planted at once, those in the lower two weeks after the green manure was turned under. Note that where only 5000 pounds per acre of green matter was turned under, the germination was reduced, and where 10,000 pounds, which is not a heavy green-manure crop, was used, the stand was nearly a failure. In a later paper, Fred [70] failed to find an adequate explanation for the injury observed, but Lumiére found that the liquid extracted from macerated dead leaves inhibited the germination of seeds and concluded "that the action of these materials on germination is due to

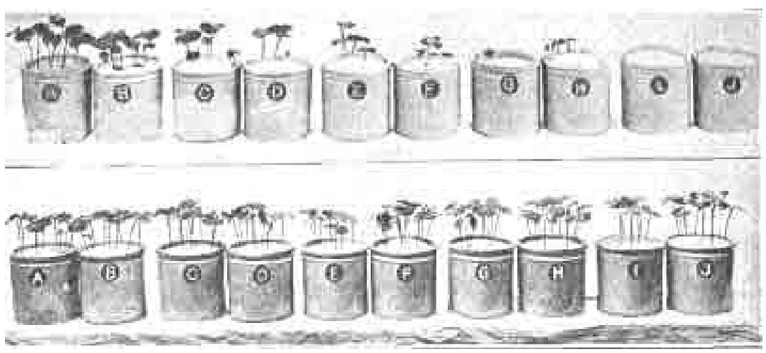

FIG. 23.—The early stages of decomposition may injuriously affect germination. In pots C to J of both rows, green manure was turned under; cotton was planted in the pots of the upper row at once, in those of the lower row after two weeks.

(U. S. Department of Agriculture.)

the fact that the solutions formed of certain of their constituents by rain water absorb oxygen from the soil at such a rate as to deprive plants of the amounts necessary in germination."

Whatever may be the cause of the ill effect referred to, it is clear that, during the early stages of decomposition, the products produced or the chemical actions set up are such as to be harmful to germinating seeds. These should, therefore, not be planted until two weeks after the green manure is turned under.

SUMMARY

Decomposition of organic matter in soils is caused by soil microörganisms, which use this organic matter for food and in doing so break down the various organic compounds and produce a number of by-products, among which ammonia and carbon dioxide are the most notable. These by-products are in turn used by other microörganisms and the ammonia is in part converted into nitrates. The more resistant organic materials, together with various decomposition products, go to make up the soil humus. The turning under of organic matter greatly increases the activities of the microflora and also their numbers. For a time the numbers of bacteria and fungi are very great, but later, as the more readily available food supply becomes exhausted, a decline in numbers sets in.

Decomposition may proceed under aerobic and under anaerobic conditions, the latter process being slower and resulting in the evolution of gases, among them free nitrogen, but nitrates are not produced. Under aerobic conditions nitrates are the most important end-products.

The rate of decomposition has been measured by the evolution of carbon dioxide, the production of ammonia and by the accumulation of nitrates. Though there are valid objections to all of these methods, the carbon dioxide method appears to be the most reliable, but is naturally only an approximate and relative measure of decay. Decomposition is dependent on moisture and temperature, but because of the various organisms taking part in the process, it is carried on under a wide range of temperature and moisture. There is, however, an optimum for each of these under which decomposition goes on most rapidly.

Lime hastens decomposition, and fertilizers, to a lesser extent, exert some influence. The rapidity of decomposition depends on the age and condition of the material turned under; young and highly nitrogenous matter decays more rapidly than that high in fiber.

Decay sets in as soon as organic matter is turned under, provided moisture and temperature are favorable and carbon dioxide may be given off even the first day. The accumulation of nitrates may be noticeable in a week and considerable in a month after the green manure is turned under. Green manures do not materially, if at all, increase soil acidity in the field, but care must be taken not to plant seeds during the early stages of decay, as injury to germination may result.

Climatic conditions are important in the decomposition of green manures and the effects produced are related to the temperature and moisture prevailing in each case.

CHAPTER VIII

BENEFITS OTHER THAN INCREASE IN NITROGEN. TYPES OF GREEN MANURING

THE effect of organic matter on the nitrogen problem has been emphasized because it is the one great problem. While the nitrogen requirements of plants can be met by the application of nitrogen salts, it is questionable whether, in the long run, this can be economically done for the common farm crops of low unit value. While, therefore, the importance of the nitrogen problem is recognized, there is danger that this increase in soil nitrogen may be considered the only benefit to be derived from green manuring. In fact, some have emphasized the need for nitrogen in such a way as to leave the impression that the sole purpose in adding green manures to the soil is to provide crop plants with available nitrogen. Such a view is the natural outgrowth of the Liebig theory of plant nutrition and, while this theory has been of great service, it takes too narrow a view of plant nutrition.

Many German writers on green manures exclude from consideration all green-manure crops except legumes on the ground that only legumes add to the nitrogen of the soil. While, of course, legumes are the most important green-manure crops, experience has shown that other plants also are useful as green manures, not only in their role of cover crops and conservers of fertility that might otherwise be lost, but because they add organic matter to the soil. It must not be forgotten that the growing of and turning under of green-manure crops, whether legumes or not, confer, besides the addition of nitrogen, certain other benefits which, while not so immediately perceived, are of great importance, perhaps the more so since they can be secured only by adding organic matter to the soil.

The Improvement of Soil Tilth.—The most striking of these effects is the improvement of soil tilth. This is a condition somewhat difficult to describe, but one readily recognized by the cultivator. The soils particles in a loam or clay in good tilth crumble readily, no hard lumps are left, and the surface works down to a fine seed bed. A sandy soil does not bake, but it, too, shows improvement from the addition of organic matter, especially in regard to its water-holding capacity. This condition of tilth is a physical one and depends, not only on the moisture in the soil, but on the organic matter. The fine particles of clay soils tend to stick together and thus exclude air as well as fail to absorb and hold the moisture. With insufficient organic matter, clay soils become hard on drying, so that the seed bed remains lumpy and throughout the season cultivation is difficult and the results unsatisfactory. Under irrigation, such soils tend to puddle and the more they are worked the worse this condition becomes, so that in time irrigation water penetrates but slowly. While this puddling is most noticeable on irrigated heavy soils, the heavy clays of humid regions also become hard and lumpy. In orchard work, where clean cultivation has been given for years, this condition often becomes especially bad, since not even weeds and crop roots are present to keep up the organic matter supply. In time, most of the original organic matter is destroyed by soil organisms and the physical condition of the soil becomes gradually worse. When this happens, the trees suffer even though commercial fertilizers are added.

One of the principal objects of cultivation is to get and to keep the soil in good tilth, so that first, a good seed bed can be made and that later a fine mulch may be maintained on the surface. Organic matter helps materially to enable the farmer to attain this object. The humus of soils is rich in colloids and, as such, it has great absorptive powers and it is believed that the fine particles of humus tend to surround each mineral particle with a thin protective layer, retentive of moisture and able to absorb and hold bases, and that this absorptive power plays an important part in regulating the supplies of phosphorus and potassium in soils. Aside from the part of organic matter represented by humus, there is a certain amount of undecomposed or partially decomposed coarse organic matter which tends, in clay soils, to improve aeration and, in coarse sands, to delay the percolation of water, a matter of the utmost importance in such soils.

It is true that the value of organic matter in supplying nitrogen and in improving the physical condition of the soil can not be sharply separated. The same organic matter necessarily performs both functions, for organic matter of any kind, stubble, roots, plant residues and non-legumes as well as grass sod contributes equally with legumes to the physical improvement of soils. The great value of sod for turning under has long been known and a large part of this value lies in the improvement of the soil tilth. In this respect, green-manures perform the same function as sod or plant residues, but in many cases they can perform that function more efficiently. In some of the green manuring studies in India it was found that the chief factor in increasing the yields of wheat after green manuring was the improvement in the physical condition of the soil. Non-legumes were found to be as effective as legumes for green manuring.

Lander and associates studied the effect on wheat in India of green manuring with a legume, guara *(Cyamopsis psoraloides)*, and a non-legume, bhang *(Cannabis sativa),* and concluded "That the main factor responsible for the increase in yield is the improvement in the physical texture of soil due to the addition of the green manure." In the case of sandy soil the moisture equivalent was increased by about 2.75 per cent. A large part of the value of green manuring in the permanent plantings of tea, coffee and Hevea in the tropics depends on the physical improvement of the soils. In these plantations it is not possible to differentiate precisely the part which the legume plays as cover crop from its role as a green-manure crop. As cover, it serves to protect the soil from washing, while as green manure it is ultimately worked into the soil and by adding organic matter improves the texture and the water-holding capacity of the soil. When deep-rooted legumes are used, as is commonly the case, the roots tend to make the soil more porous and hence a better place for the growth of the fibrous roots of the main crop. The benefit to the main crop from this physical improvement of the soil is perhaps quite as great as that derived from the additional nitrogen supplied.

On sandy soils, the improvement in physical condition is reflected mostly in the greater water-holding capacity of soils well supplied with organic matter. Farmers on sandy land have found that, where green manures have been turned under, crops have not suffered as much during periods of drought as crops growing on similar land with less organic matter. Not only does the humus help to hold moisture, but by binding the sand particles together it decreases the tendency to blow and drift.

The purely mechanical effect of turning under green-manure crops is well illustrated in the case of some peat soils in northern Indiana. These soils are used largely for trucking and are fertile sweet peats, but after some years of cultivation the soil tends to become extremely fine and, consequently, to blow when dry. While these peats contain 85-90 per cent of organic matter in the dry substance, the turning under of rye, or timothy improves the texture to such an extent through binding the fine particles of peat together, that many growers regularly use some green-manure crop in the rotation. Here there is no question of nitrogen, since the soil is rich in this element and the desired effect is wholly physical.

Organic Matter Decreases the Plowing Draft.—The effect of organic matter on the physical condition of the soil is sometimes reflected in the draft of the plow when the ground is worked. In a sand or light sandy loam the draft will not be materially affected, but on heavy clays the draft may be considerably increased as the organic matter disappears and the soil becomes harder. Noll, at the Pennsylvania station, found that the draft varied roughly in inverse proportion to the percentage of organic matter in the soil, the soil with the highest percentage of organic matter showing the lowest draft and that with the lowest percentage, the highest. While the difference was not striking, it must be remembered that the soils on which the tests were made are loams.

Duley and Jones, however, came to a different conclusion as a result of work in Missouri. In this case the plats that had long received stable manure showed a slight but distinct increase in plow draft. The effect on ordinary loams is, in any event, probably slight, but on the heavy irrigated soils of the West it is a common experience to find a decided improvement in the plowing draft after a few crops of green manure have been turned under.

Effect of the Decomposition of Organic Matter on the Solubility of Soil Mineral.—It is thus seen that green manuring has two main functions to perform—to keep up the supply of nitrogen, and to maintain **a** desirable condition of tilth. This is aside from the furnishing by green manures of energy material for soil microörganisms. Both of these main functions are important and it is, in many cases, difficult to decide which function is the more important. Fortunately, the two go hand in hand, the more organic matter the more nitrogen and the better the tilth. The value of organic matter in furnishing a home and food for soil microörganisms can not be measured accurately, but is without doubt considerable; as has already been pointed out, without life a soil would be worth little as a place for crop plants. While our knowledge of the activities of soil microörganisms is in many respects incomplete, it is known that, in addition to transforming organic nitrogen into nitrates and the fixing of atmospheric nitrogen, they profoundly affect the mineral plant food materials. Just how this is done can not be fully explained in all cases, but there is no doubt that in the decomposition of organic matter, mineral nutrients can be made available to crop plants. Jensen found that "three per cent of green manure and stable manure mixed with the soil and allowed to undergo partial decomposition increased the solubility of calcium and of phosphoric acid in the soils from 30 to 100 per cent."

Lipman and associates [178] placed a mixture of tri-calcic phosphate and organic matter in small porous jars set into sand in which barley was grown. Any phosphate made soluble should have passed through the porous jar and thus have been made available, in part at least, to the barley. No benefit was observed, however, and it was concluded that organic matter did not contribute toward making the phosphate available. Truog, in studying the effect of finely cut fermenting blue-grass on floats (fine-ground rock phosphate) found no increased solubility of the floats due to leaching from the blue grass. However, he did find that large quantities of carbon dioxide were evolved from the fermenting blue grass and that this distinctly increased the solubility of the floats. The steady removal of the soluble phosphates was necessary for the continuance of the process, since as soon as the acidulated water became saturated with phosphate, the process stopped.

Bauer was unable to detect any increased solubility of rock phosphate by subjecting it to the action of decaying organic matter, though the experiments were so arranged as to permit the removal of any phosphate rendered soluble. The reason for the failure of the decaying material to act on the rock phosphate was thought to be the release of bases from the organic matter and that these bases neutralized the action of any acids produced. Bauer points out, however, that conditions in soils are different from those in his laboratory experiments "because of the capacity of soils to take up basic material, especially if they are acid."

Paddock and Whipple quote unpublished work of W. E. Sackett as showing that, when bone meal was subjected to the action of carbon dioxide, 2.11 per cent of the insoluble phosphoric acid was made soluble in an hour and 5.21 per cent in two hours. When ground phosphate rock was treated in the same way, 0.16 per cent of the insoluble phosphoric acid was made soluble in one hour and 0.28 per cent in two hours. Magnesium phosphate similarly treated yielded in one hour 16.33 per cent and in two hours, 22.35 per cent soluble phosphoric acid. When green manures are turned under, large quantities of carbon dioxide are produced and, since the soil solution acidulated by dissolved carbon dioxide is known to act powerfully on soil minerals, it is probable that the effect of green manures on the availability of rock phosphate is to be attributed to this by-product of microörganic activity.

That the turning of organic matter into the soil may make potash available was shown by Hopkins and Aumer, who for five years carried on an experiment in growing clover on soil from which all soluble potash had been extracted by the usual chemical methods. The first year almost no growth was made. Such as was made was returned to the soil and the authors state that "the results indicate that, after two years of green manuring, sufficient potassium was liberated from the ' insoluble residue ' to enable the clover to be benefited by the lime and phosphate fertilizers, so as to outyield the crops on normal soils, to which no such fertilizer had been applied."

The mineral plant food materials have their origin in the mineral particles of soils which are primarily decomposed rock. Such plant nutrients are slowly made available by weathering as the rock decomposes, but more rapidly as the result of the microörganic activities associated with the organic matter in soils. It is said by some authorities that most soils contain enough potential mineral plant food for an almost indefinite series of crops, but, in many cases, these minerals become available too slowly for the profitable production of crops. In such cases, the application of commercial fertilizers is necessary, but the addition of fresh organic matter resulting in increased microörganic activity, and the evolution of carbon dioxide, will hasten the decomposition of the rock particles and make available to crop plants more of the minerals they need. One of the indirect benefits of green manuring may, therefore, be taken to be an increased availability of soil minerals.

Shade Effect.—German writers place great emphasis on the good effects of the shade produced by a luxuriant green-manure crop, on the physical condition of the soil. The shading of the soil is said to maintain tilth and to facilitate the action of microörganisms. A part of this good effect is attributed to the covering of the soil and the consequent protection against beating rains, the effect of which, followed by sunshine, is to harden and bake the surface. There is very little exact information on this point, though LeClair found that a crop of cowpeas tended to maintain the friability of loose and of compact seed beds. In arid regions, the shade effect of a summer cover crop in orchards is believed to be important, since without such a shade the sun, reflected from the hot baked soil, may cause scald, especially on young trees. The soil under a growing crop in arid regions, where the crop is, of course, irrigated, has been found to be cool, moist, and friable, while adjacent unprotected land is hot, dry, and compact. In the southern states the shading and protecting effect of a summer green-manure crop in pecan orchards has been found to be important, Fig. 24.

The same was found by Van der Meulen to be true in rubber plantations in the East Indies. While there is plenty of rain where rubber trees are planted, there are periods of drought and during these times the soil dries and cracks to the injury of the rubber trees. Van der Meulen found that during such a period of drought the surface soil under a dense deep-rooted green-manure crop was moist and friable, while that on adjacent ground covered with a sparse growth of grass was dry and cracked. In spite of the enormous amounts of water that must have been transpired by the green-manure crop, the surface soil in which the roots of the rubber trees were developed was actually moister than that without a green-manure crop.

Shade effect in humid regions has been unduly emphasized by some writers, the claim having even been made that the physical effect of shading was the most important effect produced by the growing of green-manure crops. Wollny [347] showed that there was no truth in this view and reported the results of trials in which on one series of plots the tops of various green-manure plants were removed and the roots and stubble only turned under, on others the crops were turned under in place, and on a third series the tops from the first series were dug in on fallow. Table XXX gives the result as reported by Wollny:

FIG. 24.—The dense shade of a heavy crop of cowpeas is good for the soil.
(U. S. Department of Agriculture)

TABLE XXX

EFFECT ON PEA YIELDS OF TURNING UNDER ROOTS ONLY OF A GREEN-MANURE CROP, ENTIRE PLANT IN PLACE, OR TOPS ONLY TURNED UNDER ON FALLOW

GREEN-MANURE PLANT	METHOD	CROP Grain, Grams	Straw, Grams
White lupines	I. Plants harvested, roots left	877	1602
	II. Plants turned under in place	1283	1470
	III. Tops from I turned under on fallow	1443	1880
White mustard	I. Plants harvested, roots left	1011	1223
	II. Plants turned under in place	1192	1327
	III. Tops from I turned under on fallow	1491	1668
Vetches	I. Plants harvested, roots left	863	1066
	II. Plants turned under in place	1145	1126
	III. Tops from I turned under on fallow	1439	1603
Buckwheat	I. Plants harvested, roots left	973	1208
	II. Plants turned under in place	1006	1063
	III. Tops from I turned under on fallow	1135	1429
Fallow	IV. Fallow only	983	1237

It is evident from this table that the benefit was chiefly derived from turning under the tops, but in this case the fallow was, of course, an especially advantageous soil on which to turn under the tops. Experience with cowpeas in this country has repeatedly shown benefits from turning under the roots and stubble only, but these benefits were always less than when the tops also were turned under.

Effect of a Green-manure Crop on Rosette.—It is true that growing crops of all kinds draw moisture from the soil and lose this by transpiration. In this way, a growing crop may dry out the soil, but the loss of water in this way has a different effect from that produced by the loss

of water through evaporation from the surface of a baked soil. This difference in effect has become especially noticeable in certain apple-growing regions of the West, where apple rosette is occasionally a serious trouble. While the cause of this trouble has not been finally determined, it is believed to be associated with the alkali content of the soil.[211] It has been found that growing crops, especially legumes, tend to lower the alkali content of the soil by shading the ground and thus reducing evaporation from the surface. It is this evaporation from the surface of a bare soil that draws the alkali up, and in this case an important benefit accruing from the growing of green-manure crops is the decrease of evaporation from the soil surface, with attendant decrease in alkali in the surface soil. Apple trees affected with rosette have been observed to recover after clover or alfalfa had been grown in the orchard for a few years and the effect on the trees has been observed to be equally good when the legume crop was allowed to grow at will and decay, as when it was disked into the soil.

A similar trouble also called rosette occurs in pecan orchards in the South and here, too, the growing and turning under of green-manure crops has served to improve the health of the trees. In this case, there was no question of alkali but the trouble was traced to a lack of organic matter in the soil and was remedied when the soil was enriched with organic matter.

In this connection, mention may be made of another disease, "mottled leaf" of oranges and lemons in California, which, though not due to alkali, is believed to be controlled by the addition of green manures. In a study of green manuring in citrus groves, Mertz found that, on the green-manured plat, the percentage of "mottled leaf" was very much smaller than on other plats.

The effect of a green-manure catch or cover crop in keeping down weeds is an additional minor benefit and will be secured only when the green-manure crop makes a luxuriant growth and, consequently, completely covers the ground.

Root Action.—Much has been said about the advantage of using deep-rooted legumes and there is some evidence that there is such an advantage. Schultz placed a high value on the root action of lupines which he found penetrated to 80 or more centimeters (32 inches) and were able to pierce a layer of hard pan that existed on his field at a depth of about 40 cm. (16 inches.) Lupines were grown on part of this field as a stubble catch crop; the remainder of the field received an amount of stable manure and fertilizers calculated to furnish as much nitrogen as was furnished by the lupines. The potatoes on the part of the field previously in lupines were dark green and healthy and yielded 20,806 pounds of potatoes per acre, while those on the balance of the field yielded 13,040 pounds per acre of inferior tubers. Examination of the root system of the potatoes revealed that, where the lupines had grown, the potato roots had followed the channels left by the lupine-tap roots and had gone into the lower soil stratum from which they drew an increased supply of water. The potatoes on the other part of the same field had been unable to penetrate the hard pan, had suffered from lack of water, and had produced an inferior crop. Schultz dug out the root systems of some of these two lots of potatoes to illustrate the advantage to potatoes accruing from the power of lupines to penetrate the hard pan, Fig. 25.

Depth to Which Roots Penetrate.—It is not possible, however, to make the broad statement that legumes root deeper than cereals, root crops, or rape. Studies by Schulze have shown that, so far as depth of root systems is concerned, the cereals go quite as deep as the legumes. Schulze made his determinations on crops grown in tanks and found that winter wheat roots penetrated to a maximum depth of 277.2 cm. (more than 9 feet); oats to 247.3 cm. (8 feet 4 inches); while peas penetrated to 208.6

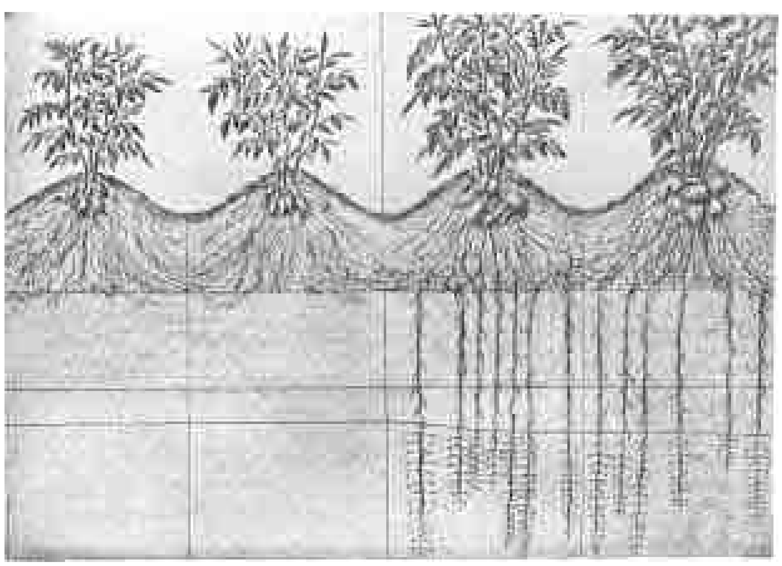

FIG. 25.—Lupine roots opened up the hardpan and the potatoes at the right followed the channels made by the lupine roots; those at the left, grown on soil without lupines, suffered from drought.
(From Schultz, Zwischenfruchtbau.)

cm. (7 feet); red clover to 209.1 cm. (7 feet); and rape to 291.2 cm. (9 feet 8 inches). Kraus collected a large amount of data on roots and showed that so far as depth of rooting was concerned the cereals sent their roots fully as deep as red clover. He cites evidence, however,to show that red clover has a larger proportion of roots in the deeper soil layers than is the case with cereals. Table XXXI shows the percentage of roots of several plants at different levels, as given by Kraus from Müntz and Girard.

TABLE XXXI
PERCENTAGE OF ROOTS AT DIFFERENT DEPTHS

Inches	Wheat	Barley	Oats	Lucerne	Red Clover
0-10	5.5	61.2	67.7	6.6	15.7
10-20	17.4	18.0	10.7	8.5	44.8
20-30	14.8	10.7	13.9	14.0	24.2
30-40	6.0	8.4	6.3	11.4	11.4
40-50	6.5	1.5	0.6	32.3	3.7

Studies of corn roots in the United States have shown that, while some roots may penetrate to depths of 4-6 feet, the great bulk of roots is in the upper 1.5 to 2 feet of soil. Alfalfa, on the other hand, has a large part of its root system at a depth below 2 feet, penetrating even in its first year to 4 and 5 feet. Peas and vetches have most of their roots near the surface, while the roots of soybeans and of cowpeas may extend to greater depths. Sweet clover has an especially powerful tap root and this has been known to aid materially in improving the drainage of stiff soils. In citrus orchards in southern California, the annual *Melilotus indica* has been found to penetrate to a depth of 8 feet. On the whole, there is evidence that the roots of such legumes as alfalfa, sweet clover, red clover, soybeans, cowpeas, and lupines do penetrate the subsoil and thus open it up especially for plants that are naturally shallow rooted, e.g., corn and potatoes.

Legumes Leave a Larger Proportion of Root Residues than Cereals. —Aside from the question of the depth to which roots penetrate, there is no doubt that most legumes leave a larger root residue in the soil than do cereals. Schulze, placing the dry weight of the above ground parts at 100, found the following figures as the dry weights of roots at various periods of growth:

TABLE XXXII
RELATION BETWEEN DRY WEIGHT OF ROOTS AND TOPS—
THE LATTER PLACED AT 100

Stage of Growth	Winter Rye	Winter Wheat	Oats	Barley	Peas	Beans	Lu-pines	Red Clover
Stooling	48.6	47.2	43.1	30.3				
Beginning to elongate					60.0	41.8	27.2	
Before winter, first yea								133.3
In milk	10.1	10.5	13.1	13.9				
End of bloom					12.7	33.4	21.4	
Second year, early spring								139.4
Second year, late spring								33.6
Ripe	4.7	9.2	11.5	9.4	6.4	13.8	17.7	
Before winter, second year								18.2

Effect of Legume Roots on the Solubility of Soil Minerals.—Roots are known to excrete carbon dioxide and by that means to affect the solubility of soil minerals. According to Dietrich, legumes have a greater effect in this regard than cereals. As quoted by Arndt, Dietrich studied the effect of weathering and of the action of plant roots on the solubility of soil minerals derived from sandstone and basalt. These rocks were ground and exposed to the weather as well as to the action of plant roots. After some time, analyses showed that lupines had dissolved from ground sandstone 23 grams and from basalt 25 grams more than had been made soluble by weathering. Peas had dissolved 16 grams more from sandstone and 24 grams more from basalt, while wheat dissolved only 0.33 gram more from sandstone and 2.45 grams from basalt.

Decomposition Products.—When fresh organic matter is turned into the soil, it is attacked *by* various microörganisms which break down the complex protein molecule into the "units, or bricks, out of which the complex structure of protein is built," [251] while the carbohydrate molecule is mainly used for energy purposes. These protein "bricks" are eventually further broken down, but meanwhile some of them, as Schreiner and Skinner have shown, can be used by plants as sources of nitrogen. How far such use is important in the field is not known, but the fact that plants can use them has been demonstrated and it is perhaps not too great a stretch of the imagination to suppose that they may appreciably supplement the nitrates in supplying the nitrogen requirements of rapidly growing crops.

These decomposition products may be of especial importance to a crop like rice, growing in water-soaked soil. Under these conditions nitrates are not produced and if present at the time when the soil is flooded are quickly lost by denitrification. If the rice crop benefits at all from the nitrogen of the green matter puddled into the soil, it must do so by taking the nitrogen as ammonia or by absorbing some of the primary decomposition products.

While some of these protein "bricks" have been shown to be harmful, they are quickly oxidized in a healthy soil. The effect on soil hygiene of the many chemical and biological reactions constantly going on in soils offers a field for important research, but there is even now good reason for believing that liming on the one hand and green manuring on the other are important factors in maintaining a healthy soil condition.[249] Bottomley believed that there are certain "growth-promoting substances" which he called auxomones in organic matter without which plants can not make the best use of the minerals available, but other workers [39] have not been able to confirm his results and the matter needs further research.

TYPES OF GREEN MANURING

Green manures may be classed under four main heads or types, in accordance with the place they occupy in the farm system: Main crops, companion crops, catch crops and winter cover crops.

1. *Main Crop.*—A green-manure crop occupying the ground during the summer to the exclusion of any other crop and not used for any other purpose may be called a main crop green manure. Such a one would be a crop of cowpeas or of soybeans planted in May and turned under in fall or the following spring. Such a green-manure crop is naturally expensive because the farmer not only pays for the seed and devotes his labor to the crop, but he gets no direct and immediate income from the land occupied.

A main crop green manure can not, therefore, be recommended, except on very poor soil which must be brought up to a state of productivity at which a regular rotation can be established. On better soils, the use of such a crop is warranted but rarely, as, for example, on some field temporarily run down and which does not yield profitable crops. In such a case, it may be better to grow a green-manure crop for a year than to expend labor on oats or corn which previous experience has shown will be produced at a loss on a given field.

2. *Companion Crop.*—It is the common practice in America to seed clovers on winter grain or with spring grain. After the grain has been harvested, the clover occupies the ground and, if the season is good, may make growth enough to cut a ton of hay per acre. Such a crop is subsidiary to the grain crop or is a companion crop, and has cost the farmer nothing but the seed and the small labor of sowing. This is perhaps the most economical form of green-manure crop and one which can be very effective. Sweet clover handled as a companion crop is extremely valuable as a green manure and has the advantage over red clover, which can similarly be used, in that farmers are more willing to turn under the sweet clover for corn than they are the first crop of red clover. Sweet clover also starts growth earlier than red clover and has made a greater mass by the time the ground must be plowed for corn. In Germany, lupines and serradella are often used in this way. It will be noted from the diagram, Fig. 26 that a companion crop occupies the ground for a longer time than any other type of green-manure crop, but does not occupy it to the exclusion of a money crop. The green-manure crops used in permanent plantations in the tropics are naturally companion crops and the same is true of summer green-manure crops in orchards in the United States. Both tree and green-manure crops occupy the ground together and make their growth at the same time, though the green-manure crop does not suffer from the competition of the main crop in the same way that clover does when growing with grain.

3. *Catch Crops.*—Crops that have a brief period of growth and are worked in after a main crop has been taken off or between two main crops, as early potatoes and wheat, are called catch crops, or, sometimes, stolen crops. The Germans call such crops "stubble crops" at least when they follow grain, as they are disked into the stubble or the stubble is plowed as soon as the grain is harvested. In Germany, lupines are very commonly used as catch crops, though they are also used as main crops and as companion crops. Mustard, rape, and turnips are common catch crops in England, while in the United States, cowpeas, soybeans, and buckwheat are chiefly seeded as green-manure catch crops. Other crops can, of course, also be seeded as catch crops and be harvested, as turnips, or as

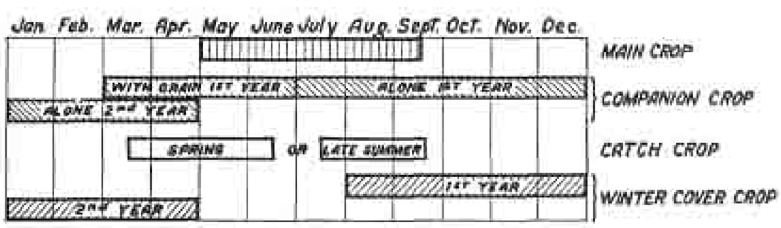

Fig. 26.—Diagram illustrating the length of time various types of green-manure crops occupy the ground.
(Drawn by L. W. Kephart from sketch by the Author.)

rape, to be fed off by hogs, but our present interest lies in the field of green-manure catch crops. A catch crop that differs from most in that it is seeded *before* rather than after a main crop is a mixture of oats and Canada field peas. This is seeded very early in spring and may be turned under for late potatoes.

4. *Winter Cover Crop.*—It was pointed out on p. 6 that the terms "cover crop" and "green-manure crop" have come to be nearly

synonymous. A cover crop may, of course, be used for some other purpose than that of green manuring. Crimson clover or hairy vetch may be cut for hay or a cover crop of rye may be allowed to mature and be harvested for grain. In orchards, too, a cover crop may be one that is killed by the cold and is merely intended to form a cover of dead plants to protect the tree roots. Cover crops have, therefore, a field of usefulness of their own, but when a "cover crop" is seeded for the purpose of soil improvement, it becomes a green-manure crop after it has served its function as a winter cover. Perhaps the most important field for green-manure cropping in the South lies in the use of winter cover crops. Aside from their value as green manures, they pay for themselves in protecting the soil and absorbing surplus nitrates. The selection of the crop to serve as a winter cover and green manure will depend on the severity of the winter in the locality in question, the time the main crop is harvested, and the nature of the main crop to follow. In the extreme north and as far south as southern Pennsylvania and Kentucky, rye, hairy vetch, alfalfa, red clover, alsike, and sweet clover are the only crops hardy enough to endure the winter. The use of all but rye is again limited by the date of harvesting the main crop. Further south, other crops, as crimson clover, will endure the winter and may be sown after wheat or early potatoes, but here the choice of the green-manure crop will be affected by the crop that is to follow. In the potato-growing section of New Jersey, rye is a very prominent cover and green-manure crop for the reason that for early potatoes the ground must be plowed at a time when even rye has not made much growth and legumes would not have made growth enough to pay. Bur clover, hairy vetch, and, in some sections, crimson clover, are very successful winter cover and green-manure crops for the cotton belt. In the California citrus groves, most green-manure crops are winter cover crops. A winter green-manure crop occupies the ground for a longer period than a main-crop green manure, but can be seeded after one money crop is harvested and can be turned under before that for the next year must be planted.

The kind of green manure selected by the individual farmer will naturally depend on the type of farming which is being carried on, whether grain or stock farming or trucking; some green-manuring crop may be fitted into almost any rotation. A successful orchardist and truck farmer near Washington uses the following rotation:

First year, corn with crimson clover at the last working.
Second year, sweet potatoes on crimson clover sod. If desired, rye may follow sweet potatoes or the land may be left bare, depending on labor and the lay of the land.
Third year, cantaloupes or tomatoes with crimson clover at the last working. The crimson clover endures trampling well.
Fourth year, corn on crimson clover sod.

This system provides for two green manure crops in three years with two cash crops and one farm crop, which may also be sold if desired.

When to **Use a Green-manure Crop.**—Green manuring in some form should be part of the regular farm practice in the northern Pacific Coast states, on most farms east of the 100th meridian and on irrigated land elsewhere. This does not mean that the production of regular crops for sale or consumption on the farm should be sacrificed, but that rotations should be so arranged as to work in a green-manure crop of some kind between regular crops. Summer green manuring with a main crop can be recommended only on poor soils, the returns from which are low, or the working of which is unprofitable. In such a case, no great sacrifice is involved when the field is devoted to green-manuring for an entire crop season. In orchards, too, the summer green-manure crop may be profitable as it does not interfere with the main or fruit crop. Green manures should be used chiefly as companion crops, as catch crops, or as winter cover crops, seeded with or after a grain crop or after potatoes that can be harvested in time for seeding. In many sections, seeding in corn or in cotton at the last working is successful. On limed or limestone land the use of sweet clover as a companion crop with grain to be turned under for corn the following year has been found profitable. On the better lands where a careful rotation, including red clover, is practiced and especially where the crop residues are cared for and returned, the practice of green manuring may not be advantageous. The turning under of the second growth of red clover is really green manuring.

The use of green manures in the semi-arid regions where dry farming is practiced is, as a rule, impracticable. The green-manure crop takes the moisture needed for the main crop and, when turned under, leaves the soil full of air spaces that cause much loss of water by evaporation. The problem of restoring organic matter to such soils is one still to be worked out.

As a rule, green manures should be used mainly on sandy or on poor lands, but evidence is accumulating to show that even some of the best lands in the United States are benefited by green manuring. There is probably no better land anywhere than that of the northern Illinois prairie and it is precisely on this land, rich in nitrogen, that sweet clover turned under for corn has given remarkable results. The cause of this is not fully understood. It seems probable that the explanation is to be found in the rapid production of nitrates from the decaying sweet clover, or possibly in the utilization by the corn of some of the nitrogenous decomposition products. Corn is a gross feeder and, while there is plenty of nitrogen in the Illinois prairie soils, the ordinary processes of decay make this available too slowly for the best growth of the corn. The decay of the sweet clover makes available a large quantity of nitrates at a time when the corn is making its most rapid growth.

Choice of a Green-manure Crop.—Whenever a green-manure crop is to be used, preference should be given to a legume if it is available, because such a crop will add materially to the nitrogen content of the soil. Where there is a choice between two or more legumes, the question arises as to which is to be preferred. Among the important points that determine the value of a leguminous crop are (1) its value as forage, both in quantity and quality, either as hay or pasture, since the practical man will always keep in mind the fact that he may need extra feed for his stock; and (2) its ability to supply additional nitrogen. Other points that deserve consideration are the cost of the seed, the ease of plowing under the crop, the deep-rootedness of the plants, their ability to choke out weeds, and the probability of getting a good stand of the crop selected. The last can often be determined only by local experience.

When the whole crop is plowed under, the effect on the subsequent crop is determined mainly by three factors—namely, the quantity of humus formed, which is directly measured by the tonnage of the crop turned under, the physical changes brought about in the soil, and the quantity of nitrogen taken from the air and added to the soil. Some authorities contend that the value of a green-manure crop depends almost wholly on the quantities of plant foods, especially nitrogen, that will be liberated by the decay of the plants. There are many data, however, which, though but little understood at present, seem to show that other factors play an important part. These little-known factors appear to be connected with the production of humus and the chemical changes associated with this process. That the production of nitrate is one very important result of green manuring is certain, and it is equally true that legumes will increase the nitrate content of the soil more rapidly than will non-legumes. The effect of various legumes depends, however, not wholly on the nitrogen content of the legume, but is in an unknown way specific. Much is still to be learned, and so far the value of different green manures has been determined wholly or mainly by the influence they may have on the succeeding crop or crops.

SUMMARY

While the maintenance of the nitrogen supply is an important object of green manuring, there are other benefits of no small importance and among these the first is the preservation of a good tilth. This is a function that is peculiar to organic matter and is closely related to the colloidal nature of humus. Good tilth can be maintained in no way so well as by keeping a soil supplied with organic matter and in this green manures, as well as crop residues, play an important part; in fact, there are conditions in which the effect of green manuring on the physical structure of the soil is more important than the quantity of nitrogen it may add to the soil.

The decomposition of plant material gives rise to carbon dioxide and this has a distinct dissolving effect on soil minerals. While it has not been proven that organic acids produced in decay can make phosphate soluble, it has been shown that the carbon dioxide produced in such decay can increase the solubility of phosphates. Green manuring thus assists indirectly in this important process. The effect which a green-manure exercises on soil tilth, on the suppression of weeds or in keeping the ground cool in arid regions and in preventing evaporation from the surface is in each case beneficial and requires for its best development a thick stand of thrifty plants. Certain diseases of orchard crops have been cured, or may be prevented by the growing of green-manure crops.

The roots of legumes can not be said to extend to greater depths than those of cereals, but a larger proportion of the entire root system of legumes does often lie at greater depths than is the case with cereals, and legumes do commonly have a larger proportion of the entire weight of the plant in the roots than cereals.

The various types of green manuring have been discussed and it has been pointed out that, except on very poor soils which must be greatly improved before they can be profitably worked, a main crop green manure can not usually be justified—it is too expensive. Green manures should commonly be used as companion, catch, or winter cover crops and of these the last-named offers the widest field of usefulness where mild winters prevail. A green-manure crop can be profitably used on all but the best soils, and sometimes even on these, whenever it is possible to grow it at small expense. Some considerations that should govern the choice of a green-manure crop are brought out.

CHAPTER IX

VARIOUS PRACTICAL CONSIDERATIONS

GREEN manuring as a practical farm operation has to do with the preparation of land, seeding, and selection of the proper green-manure crop. It involves the consideration of various limiting factors as cost of seed, diseases, etc. In the case of a legume green-manure crop, the proper nodulation of the plants must also be assured. These various practical matters are briefly discussed in this chapter.

Rate of Seeding.—The rate of seeding green-manure crops will naturally vary with the size of the seed, percentage of germination, condition of the seed bed and type of plant growth. Enough seed should be used to insure a complete cover, as only in this way can the green-manure crop, especially a summer crop, fulfill some of the secondary functions of such a crop, i.e., suppress weeds and adequately shade the ground. A much greater quantity of seed must be used than would be needed under theoretically ideal conditions; the surplus may be considered as insurance. For example, there are 300,000 seeds in a pound of red clover seed, and if 1 pound of seed could be uniformly distributed over an acre and every seed made a plant, there would be 64 plants on every square yard. At a seeding rate of 10 pounds, there would be, under these ideal conditions, 640 plants per square yard. As a matter of fact, ideal conditions never prevail and experience has shown that it is better to sow too much than too little. When seed is sown broadcast, more is needed than when it is put in with a drill, largely because in the latter case the seed is more favorably placed. Much more seed is commonly sown in Germany than is the practice in this country, and it has never been accurately determined whether the quantities commonly used in the United States in the different regions are the most advantageous. Table XXXIII gives the seeding rate commonly used or the rate suggested by experiment station authorities in this country and in Germany. The figures are for broadcast seeding. When put in with a drill, about one-fourth less can safely be used.

Mixtures of Green Manures.—Mixtures of green manures are not much used in this country except as they are also winter cover crops, as hairy vetch and rye. In Germany, a mixture of various legumes is said to give better results than any one alone. Both Schultz, whose long personal experience lends special force to his opinion, and Wagner advise mixtures of peas and vetch, or peas, vetches and horse beans as more certain to give good results than any one of these alone. In the United States most of the mixtures recommended have been primarily designed as cover crops, but in many cases at least they also serve as green manures. A successful orchardist near Washington uses a mixture of cowpeas and sorghum as a summer green manure in apple orchards. The New Jersey Agricultural Experiment Station [46] advises, besides the mixture of hairy vetch and rye, which is used everywhere, a mixture of vetch and clover. In the case of hairy vetch and rye, 15 pounds of vetch and 2 to 3 pecks of rye are recommended and for hairy vetch and clover, 15 pounds of vetch with 10 pounds of red or 5 pounds of alsike clover per acre. On sandy land Canada peas and oats seeded as soon as the ground can be worked in spring at the rate of one bushel of peas and three bushels of oats per acre make an excellent green-manure crop to turn under for late potatoes. A mixture of 40 pounds of wheat and 25 pounds of hairy vetch has been suggested as very good on wheat lands. In case this is used, care must be taken to turn under before any vetch ripens as the vetch may become a weed in wheat fields, since the seed is not easily separated from wheat.

TABLE XXXIII
RATE OF SEEDING FOR SOME GREEN-MANURE CROPS
(Pounds or Bushels per Acre)

	United States	Germany *
Alfalfa	15-20	
Barley	2-2.5 bu.	
Beans	60	
Beggar weed	8-10	
Buckwheat	bu.	
" Drilled	5 bu.	
Clover, Alsike	6	18-22
" bur, hulled	15	
" " in bur	2 bu.	
" crimson, hulled	15-20	7-35
" " unhulled	30-40	
" red	10-15	13-22
" sweet *(Melilolus alba)*	15-20	35
Cow horn turnips	1-2	
Cowpeas	120	
" in rows	15-25	
Fenugreek	35-40	
Horse beans (Windsor beans)	100-200	180-220
Lentils	60-70	
Lupines, yellow	220-240	
Melilotus indica		20-30
Mung beans in rows	10 or less	
Oats	2-2.5 bu.	
Peanuts, shelled	30-35	
" not shelled	40-50	
Peas, Canada field	60-90	125-210
Rape	5-6	
Rye	1.5 bu.	
Serradella	40-50	
Soybeans	120	
" in rows	10-30	
Timothy for cover crop	30	
Vetch, common	60-80	130-190
" hairy	30-40	

* German data mostly from Nolte.

The Rotation of Green-manure Crops.—The rotation of crops in general is advisable because, among other reasons, such an alternation of crops tends to reduce injury from insects and from fungus diseases. This principle applies with equal force to the alternation of green-manure crops on a given area. When crimson clover is grown year after year the stemrot may become so serious as to materially affect the value of the crop. On other crops, as on peas and vetches in Southern California, aphids or other insect pests may increase to a dangerous extent when their favorite food plant is grown every winter. For these reasons, change in the green-manure crop once in two to four years is advisable. Experience will have to guide in deciding for how long a term a given green manure can be advantageously grown, but as a rule, when more than one legume can be used it will be wise to change off about every third year. In orchard green manuring in the East, this practice may enable the fruit grower to adapt his labor better to the work of seeding and of plowing under the green manure.

Inoculation for Legumes.—It has already been pointed out that legumes are of special value as nitrogen gathers when they are inoculated with the proper bacteria. The visible evidence of inoculation is the formation of nodules on the roots; Fig. 27 shows such nodules on the roots of soybeans. When nodules are absent from the roots of legumes they are of no special value and, in some cases, will not even grow on a poor soil. All the bacteria that produce these nodules are believed to belong to one variable species, *Bacillus radicicola,* but there are several so-called strains, and bacteria from the nodules of one legume will not necessarily inoculate another legume. The legumes commonly used may be divided into groups according as they are or are not invaded by a given strain. Many cross-inoculation experiments have been made to establish these relationships and the present knowledge has been brought together in Table XXXIV.[1]

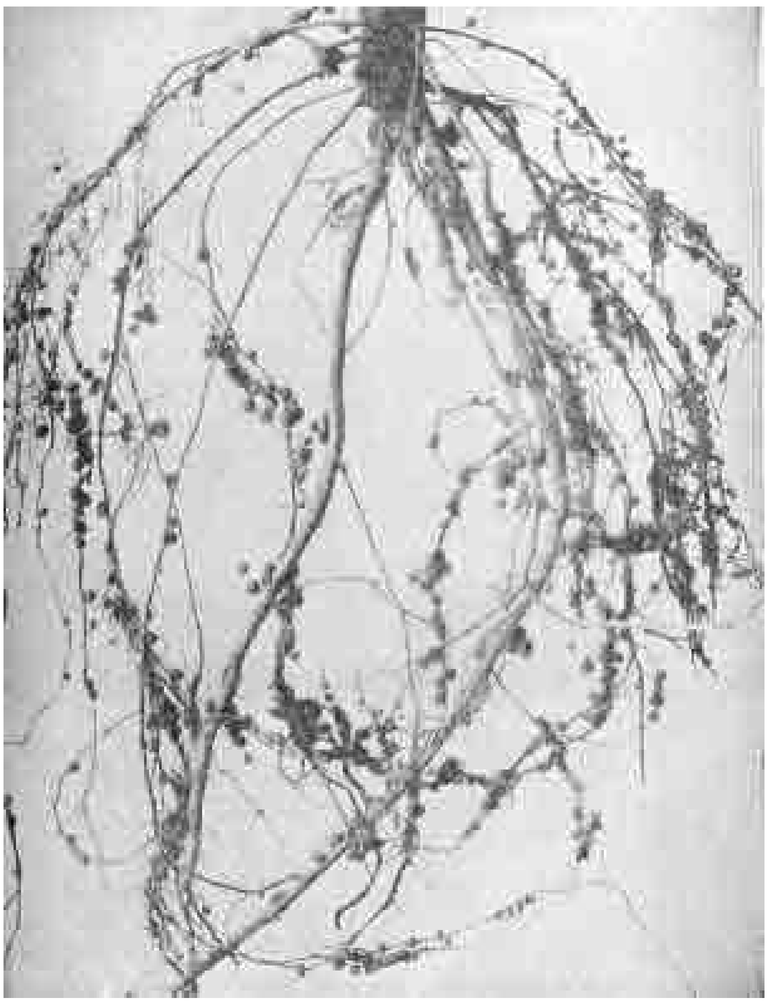

FIG. 27.—When legume roots are well noduled the plants are getting nitrogen from the air. A soybean root with many nodules.
(U. S. Department of Agriculture.)

[1] This table was kindly prepared by Mr. Lewis T. Leonard, of the Office of Soil Bacteriology, B. P. I., U. S. Department of Agriculture.

TABLE XXXIV
RELATIONSHIP OF LEGUME BACTERIA

	I. Alfalfa Group
Alfalfa	*Medicago saliva*
Yellow-flowered alfalfa	*Medicago falcata*
Bitter clover	*Melilotus indica*
California bur clover	*Medicago denticulata*
Southern bur clover	*Medicago maculata*
Button clover	*Medicago orbicularis*
White sweet clover	*Melilotus alba*
Yellow sweet clover	*Melilotus officinalis*
Fenugreek	*Trigonella foenum-graecum*
Yellow trefoil	*Medicago lupulina*
	II. Red Clover Group
Berseem	*Trifolium alexandrinum*
Alsike clover	*Trifolium hybridum*
Crimson clover	*Trifolium incarnatum*
Hop clover	*Trifolium agrarium*
Rabbit's-foot clover	*Trifolium arvense*
Red clover	*Trifolium pratense*
Mammoth red clover	*Trifolium pratense perenne*
Shaftal clover	*Trifolium resupinatum*
White clover	*Trifolium repens*
Zigzag clover	*Trifolium 'medium*
Least hop clover	*Trifolium dubium*
Buffalo clover	*Trifolium reflexum*
Carolina clover	*Trifolium carolinianum*
Small-flowered clover	*Trifolium parviflorum*
Strawberry clover	*Trifolium fragiferum*
Hungarian clover	*Trifolium pannonicum*
I	
	II. Cowpea Group
Adzuki bean	*Phaseolus angularis*
Asparagus bean	*andzeia subterranea*
Lima bean	*Phaseolus lunatus*
Hyacinth bean	*Dolichos lablab*
Moth bean.	*Phaseolus aconitifolius*
Mung bean	*Phaseolus aureus*
Sword bean	*Canavalia gladiata*
Tepary bean	*Phaseolus acutifolius*
Velvet bean	*Stizolobium deeringianum*
Florida beggarweed	*Desmodium purpureum*
Scotch broom	*Cytisus scoparius*
Blackwood	*Acacia melanoxylon*
Slender bush clover	*Lespedeza virginica*
Japan clover	*Lespedeza striata*
Furze	*Ulex europaeus*
Peanut	*Arachis hypogea*
Tick trefoil	*Desmodium canescens*
Tick trefoil	*Desmodium illinoense*
Acacia	*Acacia floribunda*
Acacia	*Acacia longifolia*
Acacia	*Acacia semperflora*
Dyer's greenweed	*Genista tinctoria*
Kudzu	*Pueraria thunbergiana*
Silky lespedeza	*Lespedeza sericea*
Cowpea	*igna sinensis*
Partridge pea	*Cassia chamaechrista*
Pigeon pea	*Cajanns indicum*
Rice bean	*Phaseolus calcaratus*
Jack bean	*Canavalia ensiformis*

IV. Vetch Group

Horse bean	*Vicia faba*
Lentil	*Lens esculenia*
Canada field pea	*Pisum sativum arvense*
Garden pea	*Pisum sativum*
Perennial sweet pea	*Lathyrus latifolius*
Sweet pea	*Lathyrus odoratus*
Tangier pea	*Lathyrus tingitanus*
Veiny pea	*Lathyrus venosus*
Woolly-pod vetch	*Vicia dasycarpa*
Hairy vetch	*Vicia villosa*
Narrow leaf vetch	*Vicia angustifolia*
Purple vetch	*Vicia atropurpurea*
Common vetch	*Vicia sativa*

V. Soybean Group

Soybean	*Soja max*

VI. Bean Group

Garden bean	*Phaseolus vulgaris*
Garden bean	*Phaseolus angustifolius*
Pinto bean	*Phaseolus vulgaris*
Scarlet runner bean	*Phaseolus multiflorus*

VII. Lupine Group

Lupine (Wild)	*Lupinus perennis*
Serradella	*Ornithopus sativus*
Blue Lupine	*Lupinus angustifolius*
Yellow lupine	*Lupinus luleus*
White lupine	*Lupinus albus*

It will be noted that the organism invading the roots of all true clovers, that is, those belonging to the genus *Trifolium,* is peculiar to that genus; the same is true of the soybean. On the other hand, the organism invading the roots of alfalfa works not only on all the species of *Medicago,* as bur clover, but also on *Melilotus,* a genus that is botanically closely related to Medicago. Again there are cases where genera apparently not at all closely related, as those in Group III of the table, are all inoculated by the same organism.

That inoculation is necessary has long been recognized, and soil inoculation appears to have been practiced in Finland long before the reason for the practice was understood. Lipman [173] states that it was formerly the custom in Finland to scatter fertile loam on newly cleared swamp land and that this practice promoted the growth of clover. Alfalfa, sweet clover, and soybeans not inoculated often make a feeble growth or die outright; Fig. 28 shows the effect of inoculation on sweet clover. In regions where a particular legume has long been grown or where another legume of the same group, according to Table XXXIV, has long been grown, the proper organisms are commonly present in the soil and the legume then becomes naturally inoculated. For example, red clover has been grown so long in the northeastern United States that the nodule bacteria are nearly everywhere present. On the other hand, in many places in the same area, alfalfa and sweet clover must be artificially inoculated. The soybean organism appears not to have been originally present in the United States and this crop has everywhere had to be artificially inoculated.

Artificial inoculation can be accomplished in various ways; by all of these the proper bacteria are introduced into the soil in such condition and location that they can invade the rootlets of the legume. It must be noted here, however, that the use of the term inoculation to designate the placing of the bacteria in the soil, while common and convenient, is not strictly accurate. Inoculation does not take place unless the bacteria enter the roots and produce nodules, and bacteria may be placed in the soil or on the seed without inoculation following. All that can be done by the various methods is to place the proper bacteria where inoculation may follow. With this explanation, the term inoculation may be used as a common and convenient term to designate the process of putting the right organisms in the soil.

Methods of Inoculation.—Three main methods are in use, the soil method, the glue method, and the pure culture method. In the soil method, a quantity of soil is taken from a field on which the legume to be inoculated has recently grown and is well noduled. Some 200 to 400

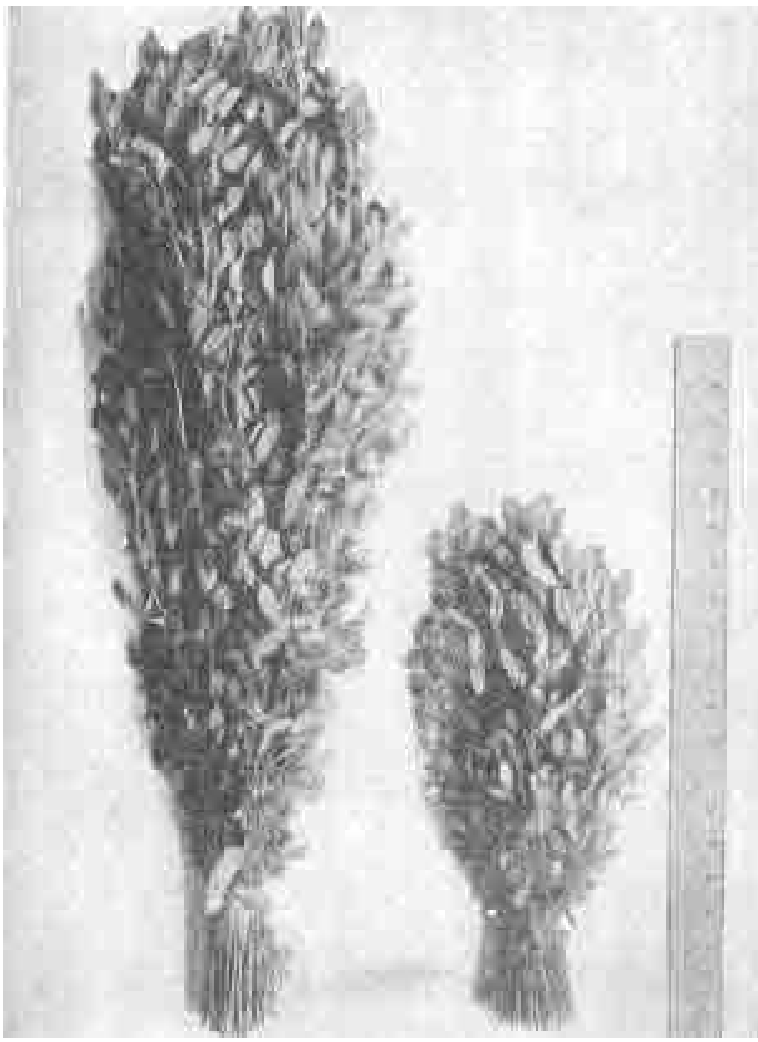

FIG. 28.—When sweet clover is grown on poor soil without inoculation, it makes little growth (right); on the same soil good growth is made when the plants are inoculated (left). (U. S. Department of Agriculture.)

pounds per acre of this soil are distributed over the new field by any convenient method, such as by drilling, by a lime or a manure spreader or otherwise, care being taken to insure a uniform distribution. The soil method is generally successful, but requires a good deal of labor and there is always a possibility that the soil may carry disease-producing organisms or weed seeds. The soil may be distributed several months before the legume crop is sown or may be stored in a dry condition for months before use. It is commonly believed that the spreading of the soil must be done on a cloudy day, since sunlight has been said to be fatal to the inoculating organisms, but the work of Albrecht casts doubt on the correctness of this statement. He exposed soil in which well-noduled crops of red clover and soybeans had been grown to drying in bright sunlight and then left it in a thin layer on a greenhouse bench where it was exposed to sunlight most of the time for two months longer. Red clover and soybeans subsequently planted in this soil were well noduled.

A method often recommended is the "glue method" in which the seed is moistened with a 10 per cent glue solution and sifted soil from about well-noduled roots is scattered over the seed. By this method or by first moistening the seed with a sugar solution, a certain amount of soil containing the inoculating germs is carried into the ground with the seed. Arny and McGinnis [16] showed that this method was not satisfactory for alfalfa, sweet clover, or soybeans, but that mixing the seed with an equal quantity of soil gave better results.

The most convenient method and one already in wide use is inoculating with pure cultures. These are prepared in various ways by several commercial concerns, as well as by a number of state Agricultural Experiment Stations and by the United States Department of Agriculture. The technique for the preparation of these cultures has been so well worked out that there is no reason why the cultures offered should not contain an adequate number of live organisms. The cultures should be used according to the directions for each make (Fig. 29).

Time and Depth to Plow Green Manures.—It has already been mentioned that, in the early stages of decomposition, green manures may exert a depressing effect on the germination of some seeds and that for this reason, among others, green manures should be turned under at least two weeks before the next crop must be seeded. Time is also needed for the seed bed to settle thoroughly.

There is also the question of whether green-manure crops should be fall or spring plowed. The answer to this will depend, in the first place, on the nature of the green-manure crop and, in the second, on what is to be done after the green-manure crop is turned under. In many cases, the demands of labor and other factors in farm management will have a deciding voice and finally the region in which the green manure is used, whether North or South, as well as the nature of the soil, will be of first importance.

Winter cover crops, as crimson clover and rye, will naturally be spring plowed and, when a crop of winter grain is to follow a summer green-manure crop, fall plowing is, of course, necessary. When a summer green-manure crop, as cowpeas, soybeans, or second-year sweet clover, is in question and a spring-planted crop is to follow, the problem of fall or spring plowing arises. This question has been somewhat extensively discussed in Germany where lupines often follow grain and are to be turned under for the next season's hoed crop, and it has been found that, on sandy land, late winter or early spring plowing is best, even though the dead lupine stems must stand on the field during winter. Von Seelhorst, from a series of studies on sandy soil in tanks, concluded that the reason for the poorer results from fall plowing was the greater loss of nitrogen by leaching. Decomposition went on in the sandy soil and the nitrates formed were lost. In several experiments with potatoes and barley following green-manure crops turned under early and late, it was found that less nitrogen was recovered in the crop and more in the drainage water when the green manure was turned under early than when it was turned under late. On heavy land, fall plowing is said to have given best results in Germany.

FIG. 29.—Inoculating soybeans with a pure culture of the right organism. (U. S. Department of Agriculture.)

In the northern United States, where the ground freezes soon after plowing, and especially where a rather mature or woody crop is turned under, fall plowing is not likely to result in loss. In such a case, the decomposition that may take place in winter and early spring will merely prepare the way for a rapid conversion of organic nitrogen into nitrates during the late spring and early summer months. In the South, however, where, during a great part of the winter, temperature and moisture are favorable for decomposition and nitrification, fall plowing of a green-manure crop should not be practiced, unless a fall-seeded crop is to follow. If no fall crop can be put in, it will be better to leave the green-manure crop on the ground for a winter cover and this is especially true of soils that wash badly. However, when a crop of cowpeas is allowed to stand in the field over winter the loss of organic matter is great and a winter green-manure crop is much to be preferred. Fall plowing in the North is often practiced because it saves spring work or, as in Iowa, because the heavy soil dries so slowly in spring that plowing and all other spring work is seriously delayed. In such circumstances, a sweet clover green-manure crop is sometimes turned under at the end of its first season's growth. Considering only the green-manure crop, this is not desirable, but from the standpoint of farm management it may be necessary. There will be, as shown on p. 208, little, if any loss of nitrogen from late fall plowing of sweet clover, but unless the plowing is very carefully done and the ground well disked the following spring, the sweet clover is likely to come up thickly from the unkilled buds and so make trouble in the corn crop. Where farm work allows it, plowing under sweet clover in early May, when 8 to 12 inches high, is probably the best practice.

As the summers in the United States are hot and decomposition is rapid, a crop of red or of sweet clover plowed under about two weeks before corn-planting time decomposes and furnishes nitrates for the corn at a time when it is growing most rapidly. If red clover is to be turned under for wheat, late July plowing has been found to give best results.

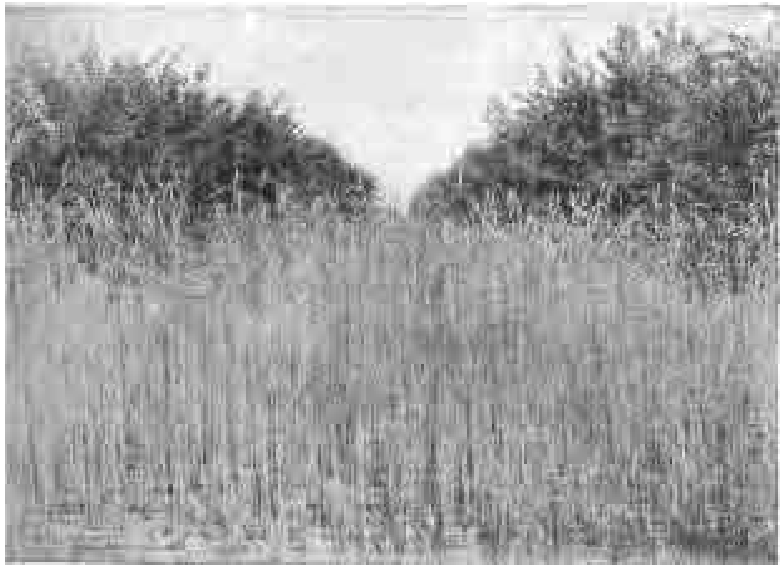

FIG. 30.—Rye should never be allowed to become as old as this before being turned under. (U. S. Department of Agriculture.)

The time to plow under a winter green-manure crop in spring will also depend on the crop to follow. In the South, cotton is planted earlier than corn and is also more easily injured than corn by being planted too soon after the green-manure crop is turned under. For cotton, therefore, plowing must be done earlier than for corn. At the Maryland Agricultural Experiment Station,[333] it was found that the best yields of tomatoes followed when crimson clover was turned under early, just before the blossoms opened. In the early potato section in Long Island and New Jersey, plowing is necessarily done in late February or early March, no matter what growth the green-manure crop has made. There are also special cases where the time of plowing is of importance, because of the effect it has on the following crop. Green found, for example, that a spring-plowed red-clover crop directly preceding tobacco had a tendency to injure the texture of the leaf. The cause of this effect is not known, but fall plowing of the clover is recommended. Howard and Howard [126] found that, if Sunn was turned under as a green manure and tobacco plants were set two months later, good results followed, while if planting was delayed to three or three and one-half months the tobacco plants made a poor growth. It is not clear why the nitrates resulting from the decay of the green manure should have been lost during the four or six weeks after the optimum date for planting, but repeated experiments showed that the time interval between turning under the green manure and setting out the tobacco was of the greatest importance.

In orchard green manuring, the case is somewhat different and the character of the orchard and region, as well as farm management considerations, will control. In the North, the protective cover crop is the thing wanted and spring plowing of the cover, whether dead or alive, is necessary. Further south, a part of the orchard, especially when a heavy summer green-manure crop has been grown, may be advantageously fall plowed so as to insure that there will be ample time to turn under all the live winter crops in spring, before the soil becomes too dry. A green-manure crop of rye should never be allowed to come into bloom before being turned under, for the older it gets, the more moisture it takes from the soil and the slower the rate of decay after it is turned under, Fig. 30. In this connection, see the discussion of the effect of turning under straw. The depth of plowing appears to be of minor importance as far as decay of the green-manure crop is concerned, except in the South, especially in the citrus groves of southern California. Here, because of the high temperatures and excessive aeration of the surface of cultivated soils, deep plowing is strongly advised.[202] On sandy soils, the green manure should be turned under more deeply than on heavy soils.

Plowing and Compacting.—The turning under of a green-manure crop interrupts the capillarity of the soil especially if the crop is heavy, and hence it is important so to turn the furrow and later so to compact the soil as to minimize this effect as much as possible. The furrow slice should be turned slanting and not flat; with a slanting furrow the plant material will

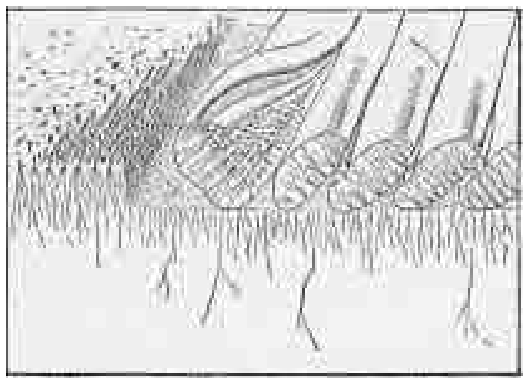

FIG. 31.—In turning under green manures, do not turn the furrow slice flat, leave it on edge.
(From Lyon, Fippin and Buckman. Copyright, The Macmillan Co.)

be more thoroughly mixed with the soil than when the furrow is turned flat, Fig. 31. An exception must, however, be made in the case of plowing biennial sweet clover in the fall of its first year. Experience has shown that if the sweet clover is turned completely over, which is done when the furrow slice is laid flat, there is less danger of a volunteer growth from the dormant buds the following spring than when the furrow slice is placed on edge. When the green-manure crop is heavy, it is well to cut it up with a sharp disk before plowing and in some cases it has been found advantageous to run a planker over the green-manure crop and lay it flat in the direction in which the plowing will be done. A chain or a number 9 wire attached to the back of the plow beam and to one end of the whiffletree will help to turn the mass of plant material into the furrow. After plowing, the soil should be well-compacted and this may be done with a heavy disk or better with a cultipacker. Compacting will bring the plant material into intimate contact with the soil, hasten decay, and restore capillarity in the soil Fig. 32.

FIG. 32.—After turning under a green-manure crop, the ground should be well compacted. (Photograph by L. W. Kephart.)

Fertilizing the Green-manure Crop.—One of the most important considerations in growing a green-manure crop is to get a large yield. A thick stand and luxuriant growth will not only yield a greater amount of green matter to turn under than a light crop, but, if the crop is a legume will materially increase the amount of nitrogen taken from the air and added to the soil. It will also shade the ground more, which in a summer green-manure crop is important, not only because weeds are thus suppressed, but because a well-shaded soil remains in better physical condition than a baked one. The green-manure crop should therefore be given mineral fertilizers when necessary, though unfortunately there is an idea that a soil-improving crop can take care of itself. With legumes, this is true only for nitrogen, if the legumes are well inoculated, but the nitrogen they are able to take from the air will depend to a certain extent on how abundant is the supply of minerals available to them. When a green-manure crop follows a grain or a hoed crop that has been liberally fertilized, the green-manure crop will utilize the residue of the fertilizers, but too often the preceding crop has not been given any more fertilizer than it needs and there is little left for the green-manure crop. The result is a smaller crop than would otherwise have been secured with the consequent lack of full effect on the crop to follow the green manure. It may also be pointed out that any minerals applied to the green-manure crop are not wasted, even if more than really needed are applied, for it is well-known that phosphates and, to a less extent, potash are fixed in the soil and thus any residue not absorbed by the green manure will remain for subsequent crops. All the minerals absorbed by the green manure will be returned to the soil and become available for the following crops.

The amount of fertilizer to apply will vary with conditions, but if it is desired to improve a poor soil, the green-manure crop should be liberally fertilized. Where it is known that otherwise good soils are deficient in phosphorus or potash, it will pay to supply the green-manure crop with the necessary element. In general, 300 pounds of acid phosphate and 100 or 200 pounds of potash salts per acre, either alone or together as may be needed, will be found to benefit the green-manure crop.

Use of Straw as a Green Manure.—Straw, especially grain straw, is poor in nitrogen and relatively rich in carbohydrates, especially cellulose. It does not, therefore, constitute what may be called a balanced ration for the soil microflora. The nitrogen-carbon ratio of most arable soils of average fertility is about 1 : 10 or 1 : 13 but, when large amounts of organic material rich in carbon are turned into the soil, this ratio is upset and a large amount of carbohydrate is made available to the soil organisms without a corresponding increase in nitrogen. The result is that during the decay of the straw the microörganisms must draw on the soil nitrates for nitrogen and crops planted after the straw is turned under are likely to suffer from nitrogen hunger. Precisely the same processes go on when legume straw or old material such as nearly ripe rye is turned under, except that in this case a certain amount of ammonia will be released from the decaying material and this can serve as a source of nitrogen to the microflora.

The degree to which crop plants may suffer from nitrogen hunger when grain straw, corn stover, legume straw or similar material is turned under will vary with the circumstances of each case. The quantity and composition of the material, the nitrate content of the soil, the time that elapses between turning under the material and sowing the following crop, moisture and temperature, all of these will influence the result. The condition of minimum nitrate content of the soil has been found to persist until all the easily decomposable carbon compounds have been destroyed and lost as carbon dioxide. Sievers and Holtz [262] studied the effect on the nitrate content of the soil of adding straw and wheat plants containing various percentages of nitrogen, 0.5 per cent for straw, and 1.01 to 4.22 per cent for wheat plants. After sixty days the nitrate nitrogen in the soil in parts per million varied in direct proportion to the percentage of nitrogen in the material turned under and ranged from 2.3 parts per million after straw to 81.7 parts per million after wheat plants, which had contained 4.22 per cent of nitrogen.

The addition of a source of nitrogen, as ammonium sulphate or ammonium carbonate, has been found to hasten decay of straw and to overcome the depressing effect of straw on the accumulation of soil nitrates. This principle is involved in the production of the so-called artificial manure from straw introduced by Hutchinson and Richards. A quantity of nitrogenous material is added to straw and this is kept moist until decomposition has been completed. The nitrogen added is transformed into organic nitrogen in the bodies of the bacteria causing decomposition and becomes a part of the manure. Whether this process will prove to be practical and economical remains to be seen. Sievers and Holly [263] showed that the addition of vetch to straw lessened the depressing effect which the straw alone exerted on nitrate accumulation.

While, for the reasons above given, straw and woody material may result in a decrease in the amount of available nitrates in the soil, such material may also have a possible beneficial effect. Hiltner and Peters concluded that, when fresh green manure is turned under, there is a considerable waste of nitrates because decay and nitrification proceed faster than the current crop can utilize the nitrates. The addition of some straw to the green manure resulted in slower nitrification and in the transformation of some of the nitrates into organic nitrogen which, in turn, became available to a later crop. Sievers found that the "high nitrate content of the soil following the plowing of a legume sod frequently causes lodging or 'burning' of the succeeding grain crop. When straw is spread on such sod before plowing, this difficulty can be largely overcome in that such application regulates the rate and kind of decomposition and thus controls the nitrate development. This practice provides for the practicable utilization of straw for the maintenance of organic matter and at the same time distributes the beneficial effects of the legume crops over a greater number of years." On the other hand, it should be added that Störmer found no increase in the yield of the second crop grown after the application of straw and he concluded that the nitrates had not been transformed into organic nitrogen, but had been lost by denitrification. This subject has been too little studied to make it possible to state definitely what happens. Like so many problems connected with green manuring, a little is known, but much more remains to be discovered.

The Application of Stable Manure to Green Manures.—The fact that the application of small quantities of stable manure to green manures just before these are turned under is beneficial has been known for a long time. Schultz commented on it as a result of his personal experience and farmers commonly spread stable manure on the clover sod before plowing for corn. Lipman and associates [179] found that the increase in yields following the application of stable manure to green manure was greater than could be expected from the fertilizer effect of the manure used and they attributed the effect to the addition of large numbers of bacteria to the soil with the manure. Others believe that the additional nitrates have merely stimulated bacterial activity while some deny that any marked effect is to be observed. The practice of using a small amount of manure when turning under green manures appears to be a good one, whatever the explanation may be and is justified by long experience on the part of green-manure users.

Effect of Some Crops upon Those Following.—It has long been known that crops differ in their effect on succeeding crops, but practically nothing is known as to the cause of this phenomenon. Some have attributed the effect to the exhaustion of soil nutrients, others to the physical condition of the soil after certain crops, but neither of these explanations seems satisfactory. It has been suggested that some crops excrete toxins which are harmful to other crops when grown on the same soil immediately afterward. Sewell found that wheat subjected to the leaching from soil in which Kafir had grown, made a poor growth, while leach-ings from corn soil had no such depressing effect. Skinner studied the failure of cabbage to grow after sesamum and found in the sesamum soil an oily substance which stunted the cabbage, but had little effect on wheat. More recently this matter has been studied in the field by Hartwell and Damon, who found very great variations in yields of certain crops as these followed one or another of several grown previously. Liming decreased these differences. This work was later extended by means of pot cultures,[107] and the results substantially confirmed the former work. There was no evidence that the withdrawal of nutrients by a crop had anything to do with the good or bad effect of such a crop on the following crop.

Among the most interesting observations on this subject are those made by Garner, Lunn and Brown, who found that the growth of tobacco was very unsatisfactory after soybeans had been turned under and that tobacco did not benefit from the green-manure nitrogen as did corn, Fig. 33. This point is of special interest, since in the tropics green manuring has decidedly benefited tobacco, though it appears from the work of Howard, mentioned above, that the time of setting out the tobacco plants is important. While it is clear that crops vary in their response to the effect of a preceding crop, nothing is definitely known as to the cause of this effect and, with the exception of the depressing effect of soybeans on tobacco, it is not clear how this crop effect may influence the choice of a green-manure crop.

FIG. 33.—The soybean is not a good green-manure crop for tobacco. The plat in the center shows the slow and uneven growth after soybeans.
(U. S. Department of Agriculture.)

Some Limiting Factors in Green Manuring.—Green manuring, as any other farm practice, is ultimately controlled by the economic results of the practice. If costs are excessive or returns inadequate, green manuring will fail as the use of fertilizers will fail. One of these limiting factors is the cost of seed.

The Cost of Seed.—It is not possible to say precisely how much a farmer can afford to pay for the seed for a green-manure crop, but obviously the seed must be both cheap, or at least not excessively high in price, and must always be readily available. This is one of the limiting factors in the use of hairy vetch. The seed is usually rather high in price and a fairly heavy seeding is necessary, so that the cost per acre runs up. In the use of green-manure crops in the California citrus groves, the cost of seed has been especially studied. A crop like *Melilotus indica* finds favor because of the low price of seed, although another crop, like purple vetch, would be preferred were it not that the seed is expensive. Horse beans too are excellent for green manure, but the large size of the seed makes the cost per acre excessive. The small cost of seed is one of the strong points in favor of rye, the seed of which is always cheap and plentiful, and of sweet clover, the seed of which commonly sells for about half the price of red clover seed. Attention should, at this point, be called to the fact that the price per unit weight or measure is not the only factor in the cost of seed. The size of the seed, that is the number of seeds per pound or per bushel, must be considered, as this affects the rate of seeding. As an example, the unit cost and the cost per acre for four varieties of soybeans may be examined as given in Table XXXV.

TABLE XXXV

RELATION BETWEEN PRICE PER BUSHEL AND COST PER ACRE OF SOME SOYBEANS

	Number of Seed, per Bushel	Acres Seeded, per Bushel	Price per per Bushel	Cost per Acre
Ototan	368,600	6-8	$9.00	$1.50-$l. 13
Laredo	466,500	6-8	8.00	1.33-1.00
Virginia	207,300	3-4	4.00	1.33- 1.00
Mammoth	129,000	2	3.00	1.50

The Otootans cost, at present, three times as much as Mammoths, but, because of the smaller seeds, the Otootans go three times as far, so that the net cost per acre is the same, Fig. 34.

Seed of green-manure crops must always be readily obtainable. Sweet clover, red clover, alfalfa, rye, buckwheat, cowpeas, and soybeans are always to be had, even if orders must be placed on short notice. Within recent years, there has been great interest in Hubam, the annual white sweet clover, but as the first interest declined the seed supplies declined also and some who would have used this new green-manure crop turned to other crops, because seed of Hubam was not readily available.

Possibility of Harboring Pests.—When a green manure is used, account must be taken of the insect pests and plant diseases that may injure the main crop and may be harbored by the green manure. In the

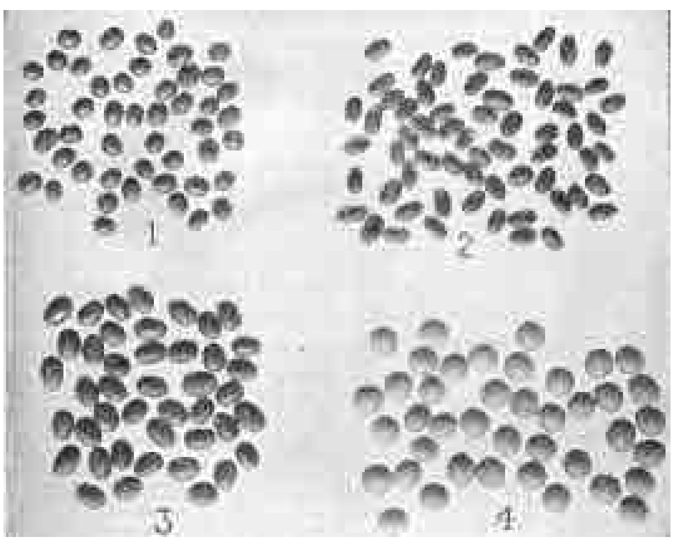

FIG. 34.—Soybeans vary in size and consequently in number per bushel. The smaller the seed the less the quantity by weight that must be used for seeding. 1, Otootan; 2, Laredo; 3, Virginia; 4, Mammoth. (U. S. Department of Agriculture.)

South, the cowpea is a valuable green-manure crop for young pecan orchards, but when these come into bearing, cowpeas can no longer be used in the orchards, because the squash bug, which injures the young pecans, is also at home on the cowpea. Where the root-knot nematode, *Heterodera,* is prevalent and the main crop is susceptible, a green-manure crop seriously infected with root knot is dangerous as it tends to increase the soil infection with this pest. In such cases, it is necessary to use a green-manure crop not susceptible to root knot or to select an immune variety. Among cowpeas, such varieties immune or resistant to root knot are Brabham and Iron. Soybeans are not as susceptible to root knot as cowpeas and the varieties Laredo and Otootan are immune or nearly so. In the Hawaiian Islands, the Pigeon pea *(Cajan indicum)* is highly regarded for green manuring, but is objectionable in pineapple culture, since it harbors a nematode which also attacks the pineapple. In the East Indies, some legumes, as *Cassia mimosoides,* are said to be very susceptible to the attack of a nematode while others, as *Crotalaria usaramoensis,* are quite resistant.

Howard [125] has shown that, in Pusa, indigo planted shortly after turning under a green-manure crop, is severely attacked by *Psylla.* It is said that in Victoria, Australia, the take-all disease *(Ophiobohis graminis)* developed to a more or less serious extent on all green-manured plats. In the use of green-manure crops in the tropics as for tea, coffee, Hevea, care must be taken that the green-manure plant selected is not subject to one of the diseases also affecting the main crop.

In this connection, it may be mentioned that a green-manure crop may sometimes serve a useful secondary purpose, as *Crotalaria,* which has been found to be a good trap crop for pumpkin bugs in Florida citrus groves.

In Sumatra, *Mimosa invisa* has been found useful as a green-manure crop on resting tobacco lands, because, while itself immune to tobacco wilt caused by *Bacterium solanacearum,* it suppresses all weeds. Many of the common weeds of resting tobacco land are hosts for the wilt organism and when these weeds are allowed to grow the next season's tobacco is more strongly attacked by wilt. The growth of the *Mimosa* is so rapid that all these weeds are killed and the wilt-disease organisms largely die out for want of host plants.[259]

The association of pests with green-manure crops, as shown by the above examples, indicates that care must be taken in the selection of a green-manure crop, consequently the possibility of trouble from this source is one of the limiting factors in the use of green manures.

Frost Damage.—The possibility of such damage exists only in the citrus groves of southern California. Here winter cover crops are extensively grown to be turned under in late February or early March, and it has been claimed that the presence of a cover crop increases the frost hazard. This conviction has crystallized into an increased rate for frost insurance asked on orchards having a cover crop, since insurance adjusters have reported greater losses from the cover-cropped orchards than from adjacent orchards not cover cropped. Young has, however, questioned the correctness of the statement that cover crops increase frost hazard, and has presented data showing that near the surface the temperature in cover-cropped orchards was about 1° F. lower than in those not having a cover crop, while at a height of 5 feet the air temperature was depressed only 0.1° F. by the presence of a cover crop. The lower temperature near the ground was thought to be due to the cover acting as a windbreak and so allowing the cold air to collect near the surface. Young compared frost-damaged fruit from orchards with and without a cover crop, but found practically no difference between the two as regards the percentage of extra choice and choice fruit.

Effect of Shade on Green-manure Crops.—This is important only in orchard work, but in selecting a green-manure or cover crop for orchards, the resistance of the crop to shading must be considered. McCue discussed this point for Delaware orchards and showed that some crops could not be successfully grown after the trees reached a size where they shaded the greater part of the ground. Rape and cow-horn turnips were especially injured by shading, while cowpeas and soybeans stood shade well. Rye was found more resistant than oats and winter vetch succeeded well on shaded ground. In Maryland, cowpeas are satisfactory only in young orchards since, contrary to what McCue found in Delaware, they do not endure shading successfully. In the same orchards crimson clover grows best on the shady side of the trees, the difference being said to be sometimes very marked. The shade factor is naturally less important for a live winter cover which will be turned under for green manure in spring than for a cover which is killed by cold and must make all, or nearly all, its growth before the leaves fall from the trees. A live winter cover, like rye, crimson clover, or vetch, makes much of its growth in early spring before the trees have leafed out.

Water Requirements in Semi-arid Regions.—Green manuring has not been satisfactory in regions of light rainfall and the reason is clearly the lack of soil moisture. A green-manure crop not only removes large quantities of water from a soil while growing, but considerable quantities are needed for the decay of the green manure. Where the rainfall is light, less than 17 inches, water becomes the limiting factor. Under such conditions a green-manure crop leaves the soil too dry and even when plowed in late summer before the fall rains not enough moisture is stored to decay the green manure and to furnish water to the following grain crop.

Enemies and Diseases of Green-manure Crops.—Fortunately, green-manure crops are not often seriously affected by insect pests. In California, common vetch and field peas are sometimes injured by aphids, and Keuchenius, and also Andrews, report some of the tropical green-manure plants attacked by worms, root lice, and moulds. As stated above, the root-knot nematode may be serious on certain green-manure crops in the South. Red clover is sometimes badly infected with Anthracnose *(Colletotrichum trifolii),* which is especially severe in the southern part of the red-clover belt. Here the disease sometimes destroys or seriously reduces the stand, but more often completely destroys the crop after the hay is removed. In such case, there is no crop to turn under for soil improvement. Stem rot *(Sclerotinia trifoliorum)*, attacks crimson clover and may reduce or destroy a stand.

Acid Soils.—The choice of green-manure crops is so wide that soil acidity, unless extreme, is seldom an important factor in the problem. For the growth of such a crop as alfalfa or sweet clover, it is often the limiting factor, although cases are known in which these crops have apparently done well in "acid " soils. As a rule, however, it is a waste of time and money to try to grow alfalfa and sweet clover, except on alkaline or neutral soils or at least on soils not more than slightly acid.

Over-stimulation of Growth.—This has been found to be a danger in peach orchards in New York when clover was used as a cover and green-manure crop. The clover apparently supplied too much nitrogen and the peach trees kept on growing when they should have been ripening wood. In Oregon apple orchards, the use of a legume green-manure crop has, on occasions, had to be discontinued, because the excessive supply of nitrogen over-stimulated wood growth.

Crops to Follow Green Manures.—When a green-manure crop is turned under, a certain quantity of nitrogen will be transformed into nitrates and it is desirable that the following crop shall be able to use as large a portion of these nitrates as possible. When a second growth of red clover is turned under in late July, a winter grain, preferably wheat, must necessarily follow, but when the green manure is turned under in spring there is a wider choice. In such a case, a hoed crop should be selected and corn commonly benefits most from a green-manure crop. When a young fresh growth of green manure like sweet clover or crimson clover is turned under in spring, decomposition is rapid and only a rapidly growing and vigorously feeding crop like corn will consume the nitrates produced. Potatoes, beets, and cotton are also good crops to follow a green-manure crop, since their period of growth coincides with that of most active decomposition of the green manure. Oats are said to benefit more than wheat from a green-manure crop, but it is much better to follow the green manure with a hoed crop than with a grain.

Quantities of Green Matter Produced per Acre.—The quantities of green matter that green manures may be expected to produce per acre vary widely not only with the kind of green manure grown but with the stage of maturity and the conditions under which the crop was raised. The amount of material turned under as tops is also not the only material added. In some cases, as sweet clover turned under about May 10th, the roots may weigh as much as the tops. Biennial white sweet clover turned under in early May, may be expected to add about 4 tons of green matter per acre to the soil with as much more in roots. The annual white sweet clover turned under in fall may yield as much as 6 to 8 tons of green matter per acre, but the root growth will be much less. *Melilotus indica,* when used as a winter green-manure crop in California, has yielded 13.7 tons green as an average of five years; at Shafter, California, the yields have been 19.6 tons. In Louisiana the yields were 10 to 13 tons of green matter per acre.

Crimson clover in bloom will return 5 to 10 tons of green matter per acre. When turned under before buds appear the yield will be less, though the Delaware Experiment Station found that crimson clover seeded July 22d and harvested November 22d of the same year weighed more than 9 tons per acre. Hairy vetch, when used as a green manure, will seldom have attained its full weight and the amount of green matter will range from 5 to 10 tons per acre. In California, common vetch has yielded 10 to 12 tons, and purple vetch as high as 20 tons per acre, while yields of Canada field peas have ranged from 7.5 to 20 tons per acre. Cowpeas in the South may be expected to weigh 4 to 12 tons, according to variety and conditions; in New Jersey 7.2 tons are reported to have been produced. Velvet beans have produced as much as 20 tons per acre. One of the heaviest yielders among annual green-manure crops is the horse bean, which has yielded in California upwards of 33 tons of green matter per acre.

In Germany the average yield of lupines is estimated at about 12 tons, Serradella 10 tons, peas 10 tons, horse beans 15 tons, and mixtures of peas and vetches about 12 tons.

The perennial legumes used in the tropics are usually cut several times and the yield is occasionally very heavy. *Tephrosia Candida* is reported [120] to have produced the following quantities in each of four cuttings in tons of green matter per acre per year; 12, 12.68, 14.82, 19.42 or an aggregate of more than 59 tons. The weights of loppings from dadap are given by the same authority as ranging from 4 to nearly 12 tons per acre in one year, while *Albizzia moluccana,* another tree used in tea gardens, yielded only 4269 pounds of green material per acre as an average for twelve years. *Gliricidia maculata* produced 13.6 tons of green loppings per acre annually. *Crotalaria striata* yielded 14.5 tons in Ceylon, while in Florida the yield was between 5 and 6 tons, and in Porto Rico 16.8 tons were produced per acre.

Of non-legumes, the Delaware Experiment Station reports cow-horn turnips as producing 11,297 pounds of tops and 20,522 pounds of roots, an aggregate of nearly 16 tons per acre. At the same station, rape yielded more than 13 tons and a mixture of rye and vetch cut in spring produced 13 tons of green matter per acre.

At the New Jersey Agricultural Experiment Station, Musgrave made a preliminary study of the amounts of tops and roots in certain cover crops. The samples were taken December 27 and the total dry weight was found to be:

	Pounds per Acre
For Abruzzi rye	7262
Hairy vetch	1207
Native rye	5266
Hairy vetch and native rye	4750

In the case of rye an unusually large part of the dry weight consisted of roots.

Under favorable conditions, very large quantities of green matter may be produced, but as a rule green manures are turned under before attaining full growth.

SUMMARY

It has been pointed out that, because of the certainty that much seed will be wasted, more must be sown than would be required under ideal conditions and that in Germany larger quantities of seed are used than is the practice in the United States; that inoculation of legumes is necessary and, if the proper organism is not present in the soil, artificial inoculation must be resorted to; further, that there are varieties or strains of *Bacillus radicicola* and that these strains infect certain legumes but not others. The information at present available on this point is given in Table XXXIV.

Some matters regarding the practical application of green manures have been discussed, as, how and when to plow under a green-manure crop, especially with reference to loss of nitrates and the effect that may be exerted on the following crop. Time must be allowed for the completion of the early stages of decomposition before the following crop is planted.

In order to get the best growth of a green-manure crop and, consequently, the most benefit, mineral fertilizers should be used when necessary. The effect of straw has been shown to be to depress yields and this is believed to be due to the consumption of available soil nitrogen by soil microörganisms, which temporarily have a too-abundant source of energy material at their disposal. The proper sequence of crops should be considered, as it has been shown that crops differ in their effects on those following, though the reason for this effect is not known in every case.

Some of the factors limiting the use of green manures, such as cost of seed, possibility of harboring insect pests and diseases, effect of shade on the green-manure crop, the relation of green manuring to water requirements, and others, have been brought out to show that care must be taken in the selection of a suitable green-manure crop.

A hoed crop, such as corn, is the best to follow the turning under of a green-manure crop.

CHAPTER X

YIELDS AFTER GREEN MANURING

THE value of any soil treatment must ultimately be determined by the crop yields resulting from that treatment and information as to such yields may come either through the general experience and observation of farmers or through the more exact work of experiment stations. The observations of farmers, while subject to inaccuracies, are a not unimportant source of information, especially when the farmer evidences his faith in his own results by a continuance of a given new practice. The more exact work of experiment stations is, however, a better source of information, since, in such work, different methods are directly compared. But even in experiment station work one is confronted with the difficulties naturally inherent in field work and many of the publications on field experiments will not bear critical examination. Unfortunately, many of the experiments on green manuring in this country have not been so conducted as to exclude all factors save the one under study and, hence, results are extremely variable.

While strikingly good effects have been observed from green manuring, many of the experiments have shown but slight increases and decreased yields have been recorded. Naturally, the most clean-cut results have been secured from the most carefully conducted experiments, but there are cases where the results secured by common farm methods have been so marked as to deserve special mention. The work by the American Experiment Stations up to 1915 bearing upon the effect of green manuring on yields alone was reviewed by the author of this book and some of the data here given are taken from that review. Space does not permit of a complete presentation of all data; the object is to cite instances of what green manuring has accomplished rather than to present all cases and, for this purpose, cases have been selected that show the effect of green manuring on some of the principal crops in America, in Germany, and in the tropics.

Effect of Green Manuring on Corn Yields.—In 1900, the Alabama Station planted velvet beans on light sandy upland soil and cut a part of the area for hay; the remaining velvet beans were plowed down in late winter for corn in 1901. The corn crop of 1901 was grown on land in corn in 1900 without any green manure, on velvet bean stubble, and, on the plat green manured with velvet beans. The yields were, in bushels per acre:

Plat 1, corn after corn	13.6
" 2, corn after velvet bean stubble`	17.9
" 3, corn after velvet bean green manure	25.9

The question here is not whether it was economically sound to turn under a ton and a half of hay per acre, as this would depend partly on the residual effect [1] of the green manure, but the fact is brought out that green manuring nearly doubled the yield of corn. A similar experience was had at the same station when, in 1900, the crop of corn was 11.9 bushels per acre larger on land green manured with velvet beans than on velvet bean stubble.

[1]For a discussion of residual effect see p. 190.

Another test recorded by the Alabama Station shows that the yield of corn after turning under cowpeas exceeded that after cowpea stubble by 78 per cent. The yields on this poor upland soil were low, but the rate of gain from green manuring was considerable. In these cases, a main crop green manure was sacrificed, but in a Mississippi experiment the cowpeas were used as a catch crop, being seeded at the last working of the corn. The average increase in corn yields over eleven years was 7.7 bushels per acre. The Arkansas Station reports the yield of corn in bushels per acre as follows:

After 4 years of cotton	16.0
After 1 year of cotton	25.8
After cowpea stubble	33.6
After cowpea vines	39.7

The Tennessee Station used cowpeas as a main crop green manure for two years and followed this treatment with corn. On land without green manure the corn yielded in 1912, 10 bushels, on the land green manured for two years the yield was 31.9 bushels. A very great improvement in the productivity of the soil was brought about, but it is probable that much of the value of the first of the two green-manure crops was lost before the corn was planted. On land on which the cowpeas were hogged off for the same two years, corn yielded in 1912, 26.2 bushels, showing that the main crop green manure could be more profitably used by being hogged off than by being turned under. A better plan was followed in 1912 and 1913, when a crop of sweet clover was cut for hay in the year sown and plowed under for corn in 1913. The yield after sweet clover was 58.5 bushels per acre, after rye turned under, 41.1 bushels. In this case there was practically no expense to the sweet clover and a crop of hay was even harvested, while, when used as a green manure, the sweet clover produced a substantial increase in the yield of corn.

In Virginia, there have been some striking results from the use of crimson clover as green manure. One of these cases is described in Farmers' Bulletin 924 of the United States Department of Agriculture, and is worth citing as an example of what may be accomplished on some run-

FIG. 35.—Corn on a run-down field in Virginia; yield too low to pay the labor, much less a profit.
(U. S. Department of Agriculture.)

down soils by a proper system of green manuring. This land was in such a poor state that it was possible to grow but one crop of corn every three years, the land being allowed to "rest" the other two years. Under this system, a crop of 15 to 18 bushels of corn per acre was harvested once in three years (Fig. 35). To start the improvement of the soil on this farm cowpeas were first sown and cut for hay and crimson clover was seeded on the cowpea stubble. The clover was turned under for corn and, at the last working of the corn, crimson clover was seeded again; this practice was continued for five years, corn being grown every year and crimson clover being used as a winter green-manure crop. The third year of this practice the corn yielded 40 bushels per acre and the fifth year, 50 bushels (Fig. 36). Acid phosphate was used with the green-manuring system, but the same amounts had formerly been used also, so that the entire increase from the low yield of 5 or 6 bushels per acre per year to 50 bushels per year must be credited to the green manure. The Delaware Station grew corn on land that had been in tomatoes the year before and on land on which a heavy crop of crimson clover had been turned under. The corn on the tomato land received 100 pounds nitrate of soda per acre, but still the yield was 18 bushels less than on the clover plot. Here the clover effected a very material increase in yield.

FIG. 36.—Crimson clover as a green manure has increased the yield of corn on the field shown in Fig. 35 from less than 10 bushels per acre to 50 bushels per acre. (U. S. Department of Agriculture.)

The Virginia Agricultural Experiment Station reported in 1918 on a green-manuring experiment and Dr. T. K. Wolfe has kindly furnished the twelve-year average yields of corn, in bushels per acre, as given below:

After crimson clover turned under	37.48
After crimson clover cut for hay	35.18
Check	13.24
After rye turned under	8.95
After rye cut for hay	17.25

Nearly every year the turning under of rye has resulted in decreased yields. The cause has not been determined but may be associated with an excess of energy material for the use of soil microörganisms.

At the New Jersey Station, an elaborate and carefully conducted experiment was carried on in large cylinders filled with eight New Jersey soil types. Corn, potatoes, oats, and rye were the main crops and legume catch crops or winter green-manure crops were grown between all main crops.[174] The yields of the various crops are not given separately, but the total amount of dry matter harvested (the legumes were turned under) and the nitrogen recovered in the dry matter are recorded and the table below shows that much more dry matter and nitrogen was secured by the use of legume catch and winter green-manure crops than in any other way.

TABLE XXXVI
YIELD OF DRY MATTER AND NITROGEN ON EIGHT SOIL TYPES
(Seven-year Average for Four Cylinders)

Treatment	Dry Matter, Grams	Nitrogen, Grams
1. Lime only	485,970	4.1960
2. Lime and minerals	560,923	4.7269
3. Lime, minerals and nitrate of soda, 160 pounds per acre per year.	723,075	5.9051
4. Lime, minerals and green manure	832,172	7.3210
5. Lime, minerals and stable manure, 15 tons per acre once in two years	607,949	5.4343

In this case the green manures were the inexpensive catch crop and winter cover crop types of green manures. There was no interference with the main crop and the result was better yields and more nitrogen than were secured after 160 pounds nitrate of soda every year or 15 tons of stable manure every other year.

At the same station, corn has been grown continuously for many years; on one series of plats a winter legume has been seeded at the last working of the corn and, in another, rye has been used. Different amounts of manure have been used on various plats of both series. Table XXXVII gives the average annual yields from 1908- 921, following a legume or a rye winter cover and green-manure crop. Unfortunately there is no record of a plat without a cover crop, therefore it is not possible to say whether the rye was profitable or not, but the results do show that the turning under of a legume produced better yields than turning under rye.

TABLE XXXVII
AVERAGE ANNUAL YIELDS OF CORN AT THE NEW JERSEY EXPERIMENT STATION, 1908-1921
(Grain in Bushels, Nitrogen in Pounds per Acre)

No Manure		1000 Pounds Manure per Acre		2000 Pounds Manure per Acre		4000 Pounds Manure per Acre	
Grain	Nitrogen	Grain	Nitrogen	Grain	Nitrogen	Grain	Nitrogen
Legume Winter Green Manure							
35.9	49	39.9	55.6	7.4	53.7	38.2	54.4
Rye Winter Green Manure							
23.3	34	28.8	40.4	29.9	42.7	28.1	41.1

In every case the comparison between comparable plats shows a good increase in yields for the legume as well as an increase in nitrogen thus making the feed more valuable.

The California Experiment Station carried on for several years in southern California an experiment in which winter legume and non-legume crops were turned under for summer crops, one of which was corn. There were 9 legume plats, 4 non-legume plats with various amounts of nitrogen added for the corn and 4 non-legume plats to which no nitrogen had been added. Unfortunately, there were no plats without any green manure and it is, therefore, not known what effect, if any, the turning under of the non-legume had on yields. The average yield of corn on all legume plats was 2486 pounds, on the unfertilized non-legume plats, 1708 pounds, and on those which received an average of 102 pounds of nitrogen per acre per year, the yield of corn was 2208 pounds. (Fig. 37.) In this case, the legumes produced as much effect as more than 100 pounds of nitrogen in fertilizers.

The Central Experiment Farm at Ottawa used red clover as a companion crop in grain and turned this clover under for a next following crop. Fodder corn was grown and the effect of the clover is shown by the yields as follows:

Previous Crop	Fodder Corn, Tons
Wheat, no clover	16.40
Wheat, with clover	22.80
Barley, no clover	17.36
Barley, with clover.	23.60
Oats, no clover	15.00
Oats, with clover	20.40

FIG. 37.—Yields of corn in California after barley plowed under plus 108 pounds nitrate of soda per acre, (10); after barley alone plowed under, (12); after *Melilotus indica* plowed under, no artificial fertilizer, (13).
(University of California.)

There was a consistent increase of approximately the same amount in each case.

In Illinois "on the Oquawka field, plots growing sweet clover that was plowed under March 28 yielded 52 per cent more corn than plots not growing sweet clover; sweet clover plots that were plowed April 25 yielded 37 per cent more corn than plots that did not grow sweet clover; and sweet clover plots that were plowed May 8 yielded 35 per cent more corn than plots that did not grow sweet clover." [11] Besides showing the value of sweet clover as a green manure this Illinois experience shows that it is not always necessary to turn under a large amount of organic matter. A smaller amount of the right kind and used in the right way may be quite as effective as a larger quantity.

In Iowa, the use of cowpeas and rye as catch crops after oats and turned under in fall for the next summer's corn crop did not increase the yields of corn, but red clover seeded with oats and turned under the same fall increased the yields of corn by 11 bushels per acre.

In the present state of our knowledge, it is not possible to explain why the turning under of a green-manure crop sometimes increases the yields of the following crop and sometimes does not, but it is believed that the causes are associated with the nature of the soil and the course of decomposition. The latter will vary with the soil, the material turned under, and the time of turning under, and some of the failures may be due to one cause or another, or to a combination of causes. It is clear that green manures will increase yields and it remains for future study to analyze more accurately, than is at present possible, the factors that make for success or failure in order that success may be more generally attained.

Effect of Green Manuring on Yields of Small Grain.—The Tennessee Experiment Station conducted on three farms a series of experiments with different forms of phosphates, the plats of one series being limed and of one unlimed; on some plats cowpeas were grown and cut for hay, while on others the cowpeas were turned under. The average yields on all comparable plats showed an annual increase in wheat yields of **a** little more than 4 bushels per acre on the green-manured plats.

At the North Carolina Experiment Station, trials were conducted on two series of plots on one of which cowpeas were turned under, while on the other no summer crop was grown. Wheat was seeded every fall on all plats and these were fertilized. Table XXXVI shows the treatment and yields.

TABLE XXXVIII

TREATMENT AND 4-YEAR AVERAGE YIELDS OF WHEAT, IN BUSHELS PER ACRE, AT THE NORTH CAROLINA AGRICULTURAL EXPERIMENT STATION

TREATMENT	YIELDS	
	With Pea Vines	Without Pea Vines
No fertilizer	20.7	11.01
Kainit, 300 pounds per acre	25.42	8.96
Acid phosphate, 300 pounds Cotton seed meal, 87.5 pounds Kainit, 37.5 pounds	26.07	11.40
Cotton seed meal, 300 pounds	21.35	13.52

FIG. 38.—Wheat grown continuously in New Jersey, no green manure.
(New Jersey Agricultural Experiment Station.)

FIG. 39.—Wheat grown continuously but with a soybean catch crop grown for green manure after the wheat. Compare Fig. 38.
(New Jersey Agricultural Experiment Station.)

It is evident in this case that, while the fertilizers alone had little effect, the turning under of cowpea vines with the fertilizers produced large increases.

At the Arkansas Station, a trial with wheat following a heavy growth of cowpeas, soybeans, and velvet beans resulted in lower yields after turning under the entire growth than after turning under the stubble only. It is stated that, where the cowpeas and velvet beans had been turned under, the germination was poor and it is evident that, in this case, the green-manure crop was not properly handled. The turning under of a heavy growth may leave the ground too loose for the best growth of crops and much work still needs to be done before precise advice can be given.

The Virginia Agricultural Experiment Station has for many years carried on a green-manuring experiment with wheat as the indicator crop, paralleling the experiment with corn referred to on page 165. The results for five years were published in 1918 and the twelve-year average annual yields of wheat kindly furnished by Dr. T. K. Wolfe are given below:

After soybeans turned unde	26.02
After soybeans cut for hay	21.09
Check	16.09
After buckwheat turned under	17.42
After buckwheat cut for hay	12.94

In this case green manuring with buckwheat was not as useful as growing soybeans for hay.

The value of a green-manure catch crop is well shown by a long-term experiment carried out at the New Jersey Agricultural Experiment Station. Here wheat and rye have been grown continuously from 1909 to 1921, one plat with no green manure, Fig. 38, the other with a legume catch crop seeded after the wheat and rye were harvested, Fig. 39.

The report made in 1922 is summarized in Table XXXIX.

It is of considerable interest to note that here the legume catch crop has not only increased yields, but has increased the nitrogen in the crop and, hence, has improved the quality of the product.

TABLE XXXIX
AVERAGE ANNUAL DRY WEIGHT YIELDS OF WHEAT AND RYE, 1909-1921 WITH AND WITHOUT A LEGUME CATCH CROP
(New Jersey Experiment Station)

Plot 68 Rye, No Legume			Plot 70 Rye, Legume		
Grain, Bushels	Straw, Pounds	Nitrogen, Pounds	Grain, Bushels	Straw, Pounds	Nitrogen, Pounds
16.9	2089	24.5	22.6	3038	34.9

Plot 69 Wheat, No Legume			Plot 71 Wheat, Legume		
Grain, Bushels	Straw, Pounds	Nitrogen, Pounds	Grain, Bushels	Straw, Pounds	Nitrogen, Pounds
11.6	1330	20.6	18.1	2202	32.8

At the Central Experimental Farm in Ottawa, as well as on some of the experimental farms in the other provinces of Canada, red clover has been used as a winter cover and green-manure crop, that is, it has been seeded with small grain and allowed to stand over winter, being turned under for a summer crop. In 1897, eight twentieth-acre plats were selected at the Central Experimental Farm, four being seeded to grain with red clover, and four without clover. The clover was turned under and oats sown in 1898 and this was followed with barley in 1899, no green-manure crop being grown between the oats and the barley. Not only did the clover turned under in 1898 increase the yield of oats by nearly 30 per cent, but it also had a marked effect on the barley in 1899. In 1902, oats and other crops were planted following a grain crop with and without clover. The yields of oats in 1902 were as follows:

	Bushels
After wheat, no clover	63.53
After wheat, with clover	72.94
After barley, no clover	61.18
After barley, with clover	70.59
After oats, no clover	58.88
After oats, with clover	70.59

In each case there was a marked increase of from 5 to 10 bushels or more per acre.

At the Nappan Experimental Farm, wheat, oats, and barley were grown in 1905, after three years of continuous grain cropping with and without clover as a companion crop. The yields for 1905 are given in Table XL.

TABLE XL
YIELDS OF GRAIN, IN BUSHELS PER ACRE

	WHEAT		OATS		BARLEY	
	Plat 1	Plat 2	Plat 1	Plat 2	Plat 1	Plat 2
No clover	34.33	39.00	41.18	60.00	32.71	38.54
Clover in grain	40.00	41.67	55.29	60.85	37.92	42.92

With the exception of oats, plat 2, there has been a marked increase in yields as a result of turning under the clover.

At the Central Experimental Farm, a series of plats seeded to grain were heavily fertilized with commercial fertilizer for ten or eleven years and during this time the average yield of oats was 44.88 bushels. At the end of this time, the fertilizer applications were discontinued, clover was seeded as a companion crop in the grain, and turned under for the next grain crop. At the end of five years of this green-manure practice, the oat yields had risen to an average of 56.69 bushels; the average annual yield of wheat was increased by more than 40 per cent, and that of barley by 48 per cent. While it may be that here the clover served to make the residues of the previously applied fertilizers available, this is in itself a useful function.

In Western Canada the conditions are very different from those in the East. The soil is well stored with organic matter, which is made available by fallowing and here the turning under of green-manure crops has shown no increased yields over fallow, although there has been a marked increase in yields on the green-manured plats compared with those continuously cropped with wheat. In Minnesota also, the practice of seeding clover with grain and turning this under for the next grain crop has been carried on for many years, having been commenced in 1894. In 1916, the results showed an average annual increase from clover over the entire period of 2.6 bushels per acre. A similar experience was had in North Dakota, where also 2 to 3 pounds red clover seed per acre were seeded with grain and turned under for the following grain crop. The yields of wheat on the green-manured plats have averaged 2 bushels per acre more than on those without clover and from 2 to 4 bushels per acre more than on plats where other small grain alternated with wheat.

Green manuring has not increased grain yields in Nebraska where again the soil contains considerable stores of organic matter, and where fallowing makes this available. Field peas were turned under on one plat and rye on another, both in the bloom stage, and oats were seeded on those plats, as well as on some in corn or in spring wheat the previous year, and on summer tilled land. The yields were, oats after oats, 16.3 bushels; after rye plowed under, 21.7; after peas plowed under, 22.2; following corn and spring wheat, 19.6 and 19.4 bushels, respectively, and on summer tilled land, 27.4 bushels.

On sandy land in the San Joaquin Valley of California, green manuring followed by summer fallow during which complete decay of the green manures could take place has increased the yields of wheat over those from fallow alone, as shown in Table XLI.

TABLE XLI
YIELDS OF WHEAT ON SANDY SOIL IN THE SAN JOAQUIN VALLEY, FOLLOWING GEEEN MANURES
(Average of Two Years)

	Bushels
After fallow	33.3
After horse beans turned under	37.6
After Canada peas turned under	36.5
After rye and vetch turned under	54.0
After rye turned under	52.3
After wheat (one year only)	15.7

In Germany green manuring is used mostly for hoed crops, but there are some records showing the effect of green manures on rye. Nolte quotes Baessler as authority for the following figures, which form part of the report of an experiment to determine the best time to turn under green manures for rye.

TABLE XLII
YIELDS OF RYE GRAIN SECURED AFTER TURNING UNDER A GREEN-MANURE CROP
(All Figures in Bushels per Acre)

	After Yellow Lupines	After Blue Lupines	After White Lupines	After Serra-della	After Crimson Clover	After Sand Vetch	No Green Manure
Rye, Grain	39.87	44.53	44.82	42.63	35.95	39.38	18.12

In each case, a considerable increase in grain was secured after green manuring.

Rice has been grown in China and Japan from time immemorial and green manuring has been practiced for many centuries. It is certain, therefore, that profitable results have followed the practice. The development of the rice industry in Texas, Louisiana, and California is a matter of recent history and, on the newer lands, the need of using green-manure crops has not yet been felt. However, Chambliss has recorded a series of cultural experiments that show the value of turning under green manures for this crop in Louisiana. In the table below are given the average yields for five years from a few of the experiments recorded; the figures selected represent those showing the highest yields.

TABLE XLIII
FIVE-YEAR AVERAGE YIELDS OF RICE IN POUNDS PER ACRE FOLLOWING TREATMENT SHOWN

Treatment	
No fertilizer, average of 3 plats	1438
Dried blood, 160 pounds per acre	1544
Sulphate of ammonia, 100 pounds	1642
Sulphate of potash, 100 pounds Limestone, 200 pounds	1512
Horse manure, 2000 pounds	1539
Biloxi soybeans plowed under after beans were harvested	2353

While, in this case, the turning under of the soybeans may be considered to be the use of plant residues rather than green manuring, the distinction is one of economics rather than of effect on yields.

In India, where green manures are used as a preparation for wheat and for rice, good results have attended the practice, though there the moisture may become the limiting factor and may influence the results more than does the green manure. Allan records increased yields of 223 pounds of grain after Sunn *(Crotalaria)* and 203 pounds after Sawri *(Sesbania),* as a result of three years' trials. The unit of area is not given, but since yields are given in English units, it is presumed that the unit of area was one acre. In Madras,[285] increased yields of rice of 474 pounds per acre in 1915, and 426 pounds in 1916 were reported. In this case, the green manure was supplemented with bone meal and potash. In the Kandy district of Ceylon, the turning under of Sunn has increased yields of rice 27 and 50 per cent, and in the south of India, this green manure has increased yields 70 per cent.[207] At the Marthur [217] Farm in Mysore, the following yields of paddy rice were secured after treatment given:

TABLE XLIV
Yields of Paddy in Pounds per Acre after Green Manuring

Treatment	Grain	Straw
Control	1330	1840
Green manuring with *Crotalaria juncea*	1840	2560
Green manuring with *Crotalaria juncea* + superphosphate	2520	3400
Green manuring with eowpeas	2120	2520
Green manuring with cowpeas + superphosphate	2080	2880

Effect of Green Manuring on Cotton Yields.—Not many satisfactory records are available in experiment station literature to show the effect of green manuring on yields of cotton. Such reports as have been found relate mainly to the turning under of a summer green manure for cotton the following year and this naturally involves a considerable loss of organic matter and of nitrogen whether the green-manure crop is plowed under in late fall or is left dead and decaying on the surface during a southern winter. Winter cover crops appear not to have been much tried by the experiment stations, though the use of such crops is not uncommon and has been attended with good results. The Alabama (Canebrake) Station grew cotton after various crops, but the best yields were secured following a legume cut for hay. In one case, however, the Alabama Station secured striking results, the yields of seed cotton being 1533 pounds per acre following a crop of eowpeas turned under, 1373 pounds per acre where velvet beans were turned under, and 837 pounds per acre where cotton followed cotton without a green-manure crop. In another case, the peas were picked before being turned under and the yield of cotton was increased 32 per cent as a result of turning under the cowpea vines. At the Georgia Station, it was shown that, while the yield of cotton was larger when eowpeas were turned under than when they were removed as hay, the total cash value of crops for the two years was less for the cotton on the green-manured plat than for the cotton and the cowpea hay produced on the other plat.

In 1907, the Alabama (Canebrake) Station planted cotton on bur clover and on crimson clover turned under, and this is the only record found showing yields of cotton after turning under a winter cover crop, though in other cases the winter cover crops have been cut for hay and the stubble turned under, and in most such cases, increases in yields of cotton have followed. The record of the yield of cotton referred to above shows that the check plat yielded 784 pounds seed cotton, the plat receiving 200 pounds cotton seed meal and 240 pounds acid phosphate yielded 800 pounds, that on which bur clover was turned under, 960 pounds, and that on which 75 per cent of the crop of crimson clover was turned under, 944 pounds of seed cotton per acre. The Arkansas Station turned under cowpea vines and cowpea stubble, and the yield of seed cotton following eowpeas was 1409 pounds per acre, following cowpea stubble, 1291 pounds, and following cotton, 1008 pounds. It is stated that similar yields have been secured every year for five years.

While official records are not available, it is known that cotton growers on sandy land in South Carolina have very greatly increased the yields of cotton by turning under crimson clover. In some cases, the increase is reported to have been ten times the yield previously secured from the land. Bur clover has also been used in South Carolina as a green manure for cotton, and after two crops of bur clover have been turned under the yield of cotton has been increased 20 to 100 per cent. Miller [204] has described the case of a run-down farm in Virginia on which the yield of cotton was increased from a third of a bale to a bale of cotton per acre after a few years of a rotation of cotton with crimson clover at the last working one year, and corn with eowpeas, the next. Both corn and cotton yields increased as the soil became supplied with organic matter. On the good lands of the Mississippi delta, the yields of cotton were increased in one case by 722 pounds seed cotton per acre as a result of turning under a winter crop of red clover followed by soybeans which were hogged off. While such cases as last mentioned do not have the exactness of definite experiments, they are in a way of even greater value as a record of what has been accomplished by providing an ample supply of organic matter for the soil.

Effect of Turning under Green Manures on the Yield of Potatoes.— The turning under of one year's growth of clover grown as a companion crop has increased the yield of potatoes in Canada. In the experiments already referred to, where grain was grown with and without clover, the yields of potatoes following the grain were increased by an average of 39 bushels per acre by reason of turning under the clover.

In Southern California, various legumes and barley, the latter with and without extra nitrogen, were turned under for potatoes. The two-year average yield of potatoes after barley alone was 9732 pounds per acre, that after barley with an average of 102 pounds of nitrogen per acre was 11,711 pounds, and the average from all plats on which legumes had been turned under was 13,588 pounds. In this case, the turning under of legume green manures had a greater effect than more than 100 pounds of nitrogen in artificial fertilizer added to the barley.

An experiment conducted at the Wisconsin Station, although for only one year, gives such clear evidence of the value of red clover as a green-manure crop that it is worth mentioning in some detail. In 1905, part of a field had been in potatoes and part in small grain seeded to clover. In 1906, the clover was turned under early in June, when 8 to 12 inches high, and four plats were then laid out on the entire field. Plat I received 10 loads well-rotted manure per acre, Plat II commercial fertilizer consisting of 300 pounds desiccated bone, 200 pounds potassium sulphate, and 200 pounds nitrate of soda per acre. Plat III served as check, receiving no fertilizer and Plat IV was on the land where clover was turned under; the first three plats were on the potato land of 1905. The yield of potatoes in bushels per acre was:

	Marketable	Culls
Plat 1	183—27 pounds	13-57 pounds
Plat II	182—45 pounds	9-32 pounds
Plat III	167-45 pounds	7- 8 pounds
Plat IV (Clover)	234-28 pounds	2- 3 pounds

In this case, the clover was a companion crop and cost nothing to produce except the cost of the seed and yet the increased yield on the clover plat was 51 bushels per acre more than that secured by the use of horse manure or of commercial fertilizer.

Crimson clover seeded in corn at the last working increased the yield of potatoes in Maryland in 1895 by 50 per cent above that on adjoining land without crimson clover. Some Michigan farmers have adopted the practice of turning under a full year's growth of alfalfa as a preparation for potatoes, and it is reported by one of these that an increased yield of 60 bushels per acre results from the practice.

Potatoes being an important crop in Germany a number of studies have been made on the effect of green manures on yields. This has been especially the case on the sandy lands peculiarly fitted for potato culture, as well as for green manuring. The estate "Lupitz" consists largely of poor sand, and on this sand A. Schultz has made a notable contribution by his practical application of green manuring. During ten years of his occupancy of the estate, 1875-1884, stock was kept and stable manure used, while in 1885, the systematic substitution of green manures for stable manure was commenced. Potatoes were grown every year and the ten-year average yield for the first period was 192 bushels per acre; the average annual yield for the second or green-manuring period of ten years was 293 bushels per acre. Here there is no direct comparison between variously treated plats the same season, but an illustration of what can be accomplished in a practical way by the turning under of green-manure crops.

Clausen grew rye in 1892 and seeded lupines and early and late-sown red clover in different plats. The yield of potatoes in pounds per acre on three check plats averaged 17,104 pounds; after lupines turned under, 19,825 pounds; after early-sown red clover, 25,839 pounds; and after late-sown red clover, 19,825 pounds. In all these cases, the green manure was a companion or a catch crop, but in all cases, especially after early-sown red clover, very substantial increases in yields were secured. Schneidewind and associates [247] seeded black medic and alsike clover in barley and on other plats they seeded a mixture of peas, beans, and vetches as a catch crop after the barley was harvested. The first series ran for four years, the black medic that grew in the barley and the legume mixture that followed the barley being turned under each year for potatoes and the yields compared with those secured after barley stubble without a catch crop. The average annual yields were as follows:

	Bushels per Acre
After black medic	336.23
After legume mixture	317.23
No green manure	280.57
Increase from black medic	55.67
Increase from legume mixture	36.67

Alsike clover and black medic were seeded in wheat one year and turned under for potatoes, The yields of potatoes were:

	Bushels per Acre
After black medic	321.39
After alsike	314.56
No green manure	262.16
Increase from black medic	59.23
Increase from alsike	52.40

One more illustration of the effect of a green manure on the yields of potatoes in Germany will suffice. Lemmerman, in the course of a study on the effect of stable manure applied when a green manure is turned under, seeded lupines as a catch crop after rye. These were turned under with and without stable manure and the yields of potatoes following on these plats were compared with those secured from plats to which stable manure only had been added and with the yields from those without nitrogenous fertilizers. The quantities of green manure were carefully equalized on each plat and the same amount of stable manure used on all plats receiving stable manure. The yields of potatoes were as follows:

	Bushels per Acre
No green manure	109.70
Stable manure	150.67
Green manure	226.09
Green manure + stable manure	252.06
Increase for green manure, over check	116.38
Increase for green manure, over stable manure	75.41

In Denmark, the turning under of serradella increased the yields of potatoes by 35.63 bushels per acre and turning under red clover increased yields by 38.60 bushels per acre.

Effect of a Green Manure on the Yield of Sugar Beets.—While no experiment station data have been found in the United States covering the effect of turning under a green-manure crop for sugar beets, a number of valuable records have been made of the yields secured by farmers in eastern Colorado as a result of using sweet clover as a green manure.[198] A field which in 1922 yielded 7 tons of beets per acre was, in 1923, seeded to oats with sweet clover as a companion crop. In 1924 the field was replanted to beets, which yielded 14 tons per acre and in 1925 the same field yielded 18 tons. On another field, the average yields of beets for several years previously had been 9 tons per acre. On this field sweet clover was turned under in the fall of its first season and the yield of beets following was 13 tons per acre. One farmer produced 21 tons of beets per acre on a 17-acre field green manured with sweet clover, while the balance of the farm yielded 16.6 tons per acre. The experience of beet farmers in this section shows that the turning under of sweet clover as green manure may increase beet yields from 50 to 100 per cent.

In Germany, where the sugar beet is a major crop, many studies have been made along this line and most of them show that green manur- ing will increase the yield of beets. Schneidewind and associates [247] carried on an experiment with black medic and alsike clover as subsidiary crops, and a legume mixture as a catch crop to precede beets as has been described above for potatoes. The three-year average yields after black medic and the legume mixture and the two-year average after black medic and alsike clover are shown in Tables XLV and XLVI.

TABLE XLV
YIELDS OF SUGAR BEETS, 3-YEAR AVERAGE AFTER GREEN-MANURE CROPS
(Tons per Acre)

	Roots	Sugar	Leaves
After black medic	18.52	3.36	13.78
After legume mixture	19.09	3.44	13.75
No green manure	17.35	3.13	12.05
Increase for black medic	1.18	.24	1.74
Increase for legume mixture	1.75	.31	1.70

TABLE XLVI
YIELDS OF SUGAR BEETS, 2-YEAR AVERAGE AFTER GREEN-MANURE CROPS
(Tons per Acre)

	Beets	Sugar	Leaves
After black medic	17.84	3.39	10.59
After alsike clover	17.38	3.33	10.15
No green manure	14.85	2.90	6.37
Increase after black medic	3.00	.49	4.22
Increase after alsike clover	2.53	.43	3.79

Lemmerman used lupines and serradella as main crops and turned under the entire growth for beets. The yields of beets and leaves, fresh weight in tons per acre are given in Table XLVII.

TABLE XLVII
YIELDS OF SUGAR BEETS FOLLOWING MAIN CROP GREEN MANURE
(Tons per Acre)

	Beets	Leaves
No nitrogen	21.688	3.696
Stable manure	25.785	3.028
Lupines as green manure	34.381	4.899
Lupines as green manure + stable manure	37.765	4.943
No nitrogen	22.267	3.563
Stable manure	25.652	3.696
Serradella as green manure	33.178	5.032
Serradella as green manure + stable manure	36.206	4.676
Increase from lupines over check	12.692	1.202
Increase from lupines over stable manure	8.595	1.870
Increase from serradella over check	10.911	1.470
Increase from serradella over stable manure	7.526	1.336

Effect of Green Manuring on the Yields of Sugar Cane.—Sugar cane is grown on rich land and naturally the need of green-manure crops is not so soon felt as in the case of crops grown on poorer land. However, there is an increasing realization of the importance of organic matter, and a few striking results secured by green manuring serve to show that this practice deserves greater attention than it has so far received. The Louisiana Experiment Station began a study of green manuring on sugar cane and, as a result of trials with various legumes, found that *Melilotus indica* greatly increased the yield of cane. Reporting on these tests in 1923, Taggart gives the following four-year average number of stalks per acre, tons of cane harvested, and per cent sucrose in juice from plats with and without *Melilotus:*

TABLE XLVIII

NUMBER OF STALKS PER ACRE, TONS OF CANE, AND PER CENT OF SUCROSE IN JUICE FOR SUGAR CANE GROWN WITH AND WITHOUT MELILOTUS INDICA

(Average for 1917-1922, with 1918 and 1921 Omitted)

Number of Stalks per Acre				Tons Cane per Acre		Per Cent Sucrose in Juice	
Spring Count		Fall Count					
Clover Plat	Check Plat	Clover Plat	Check Plat	Clover Plat	Check Plat	Clover Plat	Check Plat
9041	7656	16,525	13,711	14.06	9.87	10.77	11.01

Melilotus was used here as a catch crop without interfering with the use of the land by the main crop.

Increases from the use of cowpeas as a one-year main crop green manure have been reported from Argentina.[240] In 1910, some land which had produced cane for fourteen to fifteen years and which in that year yielded about 2 tons of cane per acre was prepared and replanted to cane. The 1911 crop was a complete failure, and cowpeas were seeded, turned under May, 1912, cane planted in August, and the 1913 yield of cane was 15 tons per acre. It would scarcely be wise to attribute this entire gain to the turning under of the cowpeas, since many other factors may have contributed to the result and there is no record of a check plat, but there is no doubt that the cowpeas contributed materially to the increased yield. In India, Sunn *(Crotalaria juncea)* has been used as a green manure for sugar cane and Knight has reported that, in four years, during which stable manure was compared with Sunn, the yield from the Sunn plat was slightly greater than that from the stable-manure plat and that the cost of producing the Sunn was much less than the cost of the stable manure.

Effect of Green Manuring on Tobacco.—Green manuring has not been a conspicuous success with tobacco in the United States, though it is reported to be successful under certain conditions in the tropics. In the United States, tobacco has done best on "rested" land, but in districts where land is valuable, continuous tobacco growing is practiced, sometimes with apparent success, but often yields tend to decline. It is believed that organic matter should be worked into the soil, but so far the search for a satisfactory green-manure crop has not been wholly successful. In the Connecticut tobacco fields where the culture is very intensive, vetch was tried many years ago and more recently timothy has been used by some growers. Both crops have, however, been found wanting in permanent general value. A rotation including red clover as a full year crop, one hay crop being removed and the next turned under appears to have been the only system to compare at all favorably both as to yields and quality of tobacco produced, with the growing of tobacco on "rested" land. As far as records of yields and value of the crop are concerned, the only record found is that in a recent study by Garner and associates. Tobacco was grown in a three-year rotation of tobacco, wheat, red clover, one crop of clover being cut for hay, the other left and turned under very early in spring; with crimson clover, with hairy vetch, and with rye as cover crops in continuous tobacco culture and in two-year rotations of tobacco and wheat with crimson clover and cowpeas following wheat. All cover crops have been turned under, and the yields from these plats compared with those from plats continuously in tobacco without a cover crop. All except two plats were fertilized and the yields from these two unfertilized plats are not included in Table XLIX, since the yields from these plats were so low as to indicate that the lack of minerals was the limiting factor.

The value in dollars, being the result of yield and quality, shows that in some of these cases, though the green-manure crop increased yields, the quality was inferior. The use of red clover has increased the yield and improved the quality, while crimson clover and rye have been decidedly unsatisfactory. While the results with vetch have shown a gain, the authors point out that the fluctuations in the yield of tobacco on the. vetch plats have been large, while those after red clover have been small.

TABLE XLIX

AVERAGE 8-YEAR YIELDS AND GROSS VALUE PER ACRE, 1916-1923, FROM TOBACCO ON PLATS VARIOUSLY TREATED ON THE UPPER MARBORO, MARYLAND TOBACCO EXPERIMENT STATION

Cropping System	Average Yields, Pounds per Acre	Gross Value, Dollars per Acre
Tobacco, wheat, red clover	1166	345
Tobacco, wheat, crimson clover	989	77
Tobacco, crimson clover	892	231
Tobacco, vetch	1115	296
Tobacco, rye	759	197
Tobacco, fallow (check)	902	267
Tobacco, wheat, cowpeas	1136	267

In the tropics, good results, but often not great increases in yields, have been reported and, according to Howard and Howard,[127] green manuring can be successfully used only on "light, high-lying, well-drained soils"; if used on low, wet soils decreased yields result. The time that elapses between plowing under the green manure and planting the tobacco is also of great importance, two months being the most favorable interval. On the whole, the problem of green manuring for tobacco is one requiring much more study and at present red clover in a rotation appears to be more satisfactory than any other crop to precede tobacco in the United States. In the tropics, *Crotalaria juncea* has given good results if used as above indicated.

Effect of a Green-manure Crop on the Yield of Truck Crops.—Where intensive trucking is practiced, it is essential that maximum yields be obtained and, as a rule, stable manure and commercial fertilizers are liberally used. The increasing scarcity and cost of stable manure has made it necessary for some truckers to resort to the use of legume green-manure crops to replace or supplement the stable manure. Johnson [138] has reported the results of a trial on Norfolk gravelly loam, which had not been under cultivation for a number of years and was in a low state of fertility. On one series, crimson clover followed each main crop and was turned under for the next crop, on another 15 tons of stable manure were applied annually and on a third series no organic matter was supplied. To some plats, 4000 pounds of complete commercial fertilizer were applied per acre annually, to others 2000 pounds, and others received no commercial fertilizer. In Table L are given the average annual yields of two crops of kale and of three crops each of cabbage, white potatoes, and sweet potatoes. It will be noted that the addition of complete fertilizer was more needed with green manures than with stable manure, as the latter naturally carried considerable quantities of minerals. With no commercial fertilizer, the yields after green manure were markedly less than those after stable manure, but with commercial fertilizers the yields after green manures often exceeded those after stable manure.

TABLE L
YIELDS OF TRUCK CROPS AFTER GREEN MANURE AND STABLE MANURE,
WITH AND WITHOUT LIME AND FERTILIZERS

Crops		No Animal Manure or Cover Crops	Legumes Turned under, Winter Cover Crops	Lime and Legumes Turned under	Lime and Animal Manure Turned under	Manure Turned under, 15 Tons per Acre Annually
	4000 lbs.					
Kale	commercial	9,000 lbs.	11,310 lbs.	19,300 lbs.	17,890 lbs.	16,010 lbs.
Cabbage	fertilizer	7,904 lbs.	12,416 lbs.	19,160 lbs.	17,646 lbs.	15,760 lbs.
Potatoes	per acre	114 bu.	224 bu.	258 bu.	259 bu.	226 bu.
Sweets	annually	168 bu.	227 bu.	63 bu.	213 bu.	244 bu.
	2000 lbs.					
Kale	commercial	11,880 lbs.	13,380 lbs.	19,446 lbs.	19,000 lbs.	15,449 lbs.
Cabbage	fertilizer	9,840 lbs.	12,080 lbs.	14,480 lbs.	14,160 lbs.	13,760 lbs.
Potatoes	per acre	134 bu.	231 bu.	248 bu.	237 bu.	195 bu.
Sweets	Annually	284 bu.	237 bu.	257 bu.	288 bu.	311 bu.
Kale	No	11,965 lbs.	2,160 lbs.	5,740 lbs.	11,690 lbs.	7,960 lbs.
Cabbage	commercial	2,215 lbs.	2,700 lbs.	6,300 lbs.	8,880 lbs.	4,800 lbs.
Potatoes	fertilizer	57 bu.	72 bu.	100 bu.	131 bu.	91 bu.
Sweets		178 bu.	138 bu.	184 bu.	184 bu.	272 bu.

The Rhode Island Agricultural Experiment Station has carried on some work with green manures as a substitute for stable manure. Prior to 1922, no very definite results had been secured, partly it seems because it has been difficult to get a satisfactory leguminous winter cover crop. It is reported that "the green-manure plots yielded more cabbages than the plots receiving only manure, but about a fourth less tomatoes and celery."[103]

The shortage and high cost of stable manure have been felt among vegetable growers in England, as well as in America, and studies on the use of green manures instead of stable manure have been commenced at the Royal Horticultural Society's, Wisley Laboratory. The first report on these studies by Page [227] covers the effect of various green manures on the yields of turnips. The soil on which the experiments were conducted is described as a light sand and the green manure on one-half of the plats was turned under in autumn, that on the other half in Spring. The growth, especially that of the legumes turned under in the autumn, was small, and the increases in yields of turnips secured were not large, but the plats on which the green manure was incorporated with the soil in the spring nearly all showed good increases. Table LI gives the record for the spring-plowed section, and Table LII that for the autumn-plowed section:

TABLE LI

QUANTITY OF GREEN-MANURE MATERIAL TURNED UNDER, YIELD OF TURNIPS AND RATIO OF INCREASE IN THE TURNIP CROP TO ASH-FREE MATERIAL BURIED. SPRING SECTION

(Wisley Laboratories, 1920)

Green Crop	Fresh Green Crop. Tons per Acre	Dry Organic Matter Buried, (Incl. (Roots), Cwt. per Acre	Turnip Yield: Whole Plant		Turnip Yield: Roots Only		Ratio of Increase	
			Tons per Acre	Per Cent of Control	Tons per Acre	Per Cent of Control	Whole plant	Roots Only
Crimson clover	17.0	43.5	20.4	287	10.5	239	7.1	3.2
Vetch	8.6	23.3	18.7	263	9.7	220	13.2	6.0
Red clover	3.9	14.2	15.1	213	9.3	206	19.0	11.7
Rye	8.4	38.2	13.4	189	8.6	195	3.9	2.6
Oats*	2.7	13.0	11.4	161	7.4	168	(11.9)	(8.3)
Rape	9.3	35.1	10.6	149	6.4	145	2.4	1.4
Turnip	7.8	25.0	9.9	140	5.7	130	2.9	1.4
Lupines			9.2	130	5.9	134		
Mustard †	2.8	13.7	9.0	127	5.9	134	4.8	3.8
Control ‡	2.2 (Incl.roots)	5.8	7.1	100	4.4	100		
Black Medic	1.4	8.4	7.1	100	4.4	100		

* This crop rotted off in winter. † This crop was dying down. ‡ Fresh crop—weeds.

It is said that this work will be continued and the record of the first year certainly opens a number of interesting questions. In proportion to the amount of organic material turned under, red clover has made the best showing; in point of yields produced on the autumn section, the more rapidly growing non-legumes have given the best results, while on the spring turned section, crimson clover and vetch head the list. It is difficult to understand why black medic with a quantity of organic matter on the autumn section nearly equal to that of red clover should have given results below those from the control plot or why lupines on the spring section should have given an increase no greater than that from mustard.

QUANTITY OF GREEN MANURE MATERIAL TURNED UNDER, YIELD OF TURNIPS AND RATIO OF INCREASE IN TURNIP CROP TO ASH-FREE MATTER BURIED. AUTUMN SECTION
(Wisley Laboratories, 1920)

GREEN CROP	FRESH GREEN CROP. TONS PER ACRE	DRY ORGANIC MATTER BURIED, (INCL. (ROOTS), CWT. PER ACRE	TURNIP YIELD: WHOLE PLANT: Tons per Acre		TURNIP YIELD: ROOTS ONLY: Tons per Acre		RATIO OF INCREASE	
			Tons per Acre	Per Cent of Control	Tons per Acre	Per Cent of Control	Whole plant	Roots Only
Crimson clover.	1.7	5.7	7.0	106	4.0	103	2.2	0.6
Vetch	4.3	14.9	10.3	156	5.5	141	5.8	2.5
Red clover.	0.4	2.9	7.2	112	4.1	105	15.0	5.0
Rye	2.9	11.9	11.4	173	6.3	162	9.6	4.8
Oats	3.6	16.0	11.0	167	6.3	162	6.3	3.4
Rape	4.2	14.7	6.4	97	3.2	82		
Turnip	4.2	18.8	7.5*	114	4.3*	110	0.9	0.5
Lupine	0.4	1.9	6.3	95	3.5	90		
Mustard	5.6	21.4	10.4	158	5.9	151	3.8	2.0
Control	0.8 † (Incl.roots)	2.2	6.6	100	3.9	100		
Black medic	0.5	2.5	4.6	70	2.4	62		

* Figures from one crop only. † Fresh crop—weeds.

The Effect of Green Manuring on Orchard Crops.—Cover crops which may or may not be also green-manure crops have long been used extensively in orchards throughout the United States. There is considerable literature on the subject containing advice as to what to sow, when to sow, and when to plow, but very little definite information has been found as to the effect of a green-manure crop on yields of fruit. The general experience of fruit growers has, however, shown that it pays to grow cover crops, but the conclusion that such crops pay is founded more on the healthful appearance of the trees and the satisfactory financial outcome than upon any definite, or at least recorded, data regarding yields.

The Delaware Station was, perhaps, the first to publish some results on this matter when in 1918 McCue reported on a seven-year study with various cover crops in a peach orchard. Seven crops were used, some summer and some winter crops, and of these five gave increased yields, while the use of two resulted in decreased yields. The poor results from the use of cowhorn turnips appears to be correlated with the inability of the turnips to endure the shade as the trees became older, and the consequent very poor stands secured, while the vetch, though commonly considered to be a good winter cover crop in the North, appears not to have made a satisfactory growth in this case. The average yields secured are given in Table LIII.

TABLE LIII
TOTAL CORRECTED YIELDS FROM PEACHES VARIOUSLY GREEN MANURED.
POUNDS PER ACRE
(Delaware Experiment Station, 1911 to 1917, Incl.)

Cover Crop	Corrected Yield	Gain or Loss	Rank
Cowpeas	107,344.3	25,541.2	1
Cowpeas and rape	98,856.3	18,294.5	2
Soybeans	97,950.5	16,812.3	3
Rye and crimson clover	87,509.9	5,709.7	4
Oats	82,770.7	970.5	5
Check	81,800.2		6
Rye and vetch	80,741.7	–1,058.5	7
Cowhorn turnips	79,678.0	–2,122.2	8

It is stated that the plat green manured with crimson clover was thrown out of the tabulation because of poor location of the plat, else the showing from "this excellent plant" would have been better. Further, crimson clover on the rye and crimson clover plat failed in 1916, the ground cover consisting wholly of rye and the yield of peaches fell off in 1917. McCue states that if the crop of 1917 be disregarded the rye and crimson clover plat would rank third instead of fourth. As a green-manure crop, oats failed, since in every year but one (1912) the yield from the oats plat fell below that of the check.

In 1912, there was a great deal of killing of the buds and the oats showed its value as a cover in hastening the maturity of the buds and preventing winter injury. This quality is naturally of value where such injury is likely to occur, but is a factor in the special cover crop problem rather than in that of green manuring.

At the Montana Agricultural Experiment Station, an experiment in apple growing was started in 1908, and last reported on in 1922.[289] In the original plan, plat 1 was to be intercropped to potatoes and plat 5 was to be clean cropped, but owing to rosette making its appearance alfalfa was seeded in 1915 in plat 5 and clover was seeded from 1917 on. Plats 2 and 3 were seeded to clover, all the growth being turned under on plat 2 and all growth removed on plat 3, while plat 4 was seeded to peas. An occasional year of clean cultivation was necessary on all plats to keep down weeds. The yields of Mclntosh Red, and Rome Beauty apples are given in Table LIV,

TABLE LIV YIELDS OF APPLES, IN POUNDS PER TREE FROM PLATS VARIOUSLY TREATED

	McIntosh Red			Rome Beauty		
Plat No.	1919	1920	1921	1919	1920	1921
1	67	196	232	28	94	92
2	45	170	169	31	97	67
3	38	89	104	27	62	67
4	32	60	96	26	17	43
5	31	41	65	5	6	24

The good yields on plat 1 are attributed to the greater amount of moisture these trees had during the early years. Peas were not a desirable green-manure crop in this case and on plat 5 the trees would probably have died, had not stable manure been applied in 1917.

TABLE LV

YIELDS OF CITRUS FRUIT FROM PLATS VARIOUSLY TREATED, 1912-1916, IN POUNDS PER TREE

PLAT	YIELDS IN POUNDS PER TREE, 1912-1916			PER CENT FANCY AND CHOICE FRUIT			PER CENT DESIRABLE SIZED FRUIT 150s, 170s, 200s)		PER CENT TREE-RIPE
	Navels	Valen-cias	Lemons	Navels	Valen-cias	Lemons	Navels	Valen-cias	Lemons
B	32	33	65	69	67	34	33	26	22
F	163	414	335	72	78	41	33	33	16
O	180	379	347	65	78	62	30	28	12
U	451	570	510	71	88	62	47	54	9

The effect of a green manure on the yields of citrus fruits has been studied by the California Experiment Station and reported in Bulletin 292. The experiment ran from 1907 to 1916 and plat B was unfertilized, plat F received stable manure, plat 0 stable manure and phosphates, and plat U stable manure, phosphates and a legume green-manure crop. During the first three years, a small amount of commercial fertilizer was also used on this plat. Table LV gives the average annual yields in pounds per tree from 1912 to 1916.

As regards small fruits, the only record that appears to have been made on the effect of a green-manure crop is that by Card, who seeded crimson clover among black cap raspberries and blackberries. The yields from all plats were low, but were decidedly higher on those plats on which crimson clover had been grown and turned under than on the control plats, as shown in Table LVI.

TABLE LVI

YIELDS OF BLACK CAPS AND BLACKBERRIES, 1901 AND 1902 AT THE RHODE ISLAND STATION

(Pounds per Plat)

	1901		1902	
	Pounds	Ounces	Pounds	Ounces
Black caps with crimson clover	50	9	70	14
Black caps without crimson clover	27	6	32	7
Blackberries with crimson clover			15	15.5
Blackberries without crimson clover			7	4.5

Residual Effect of Green Manuring.—It is well known that fertilizers applied, especially if used liberally, are not all utilized by the current crop; the following crop also receives some benefit. This residual effect is marked when stable manure is used and in England the value of such residual fertilizer has been estimated and an allowance is made therefor to the departing tenant. Such residual effect would naturally be expected in the case of a green manure, because early decay is always incomplete and a part of the nitrogen in the plant material turned under during any season remains to be utilized by a later crop. Very little experimental evidence for this residual effect has been accumulated by the experiment stations in the United States, but some has been recorded by the Central Experimental Farms in Canada and a great deal by German writers. In fact, German workers on the utilization of nitrogen commonly take two crops after green manuring and expect the second to derive marked benefit from the residual effect.

The Alabama Station turned under velvet beans on certain plats in 1898 and grew cotton in 1899. The cotton yielded 660 pounds per acre more on the velvet bean plats than on the check and was followed in 1900 by corn, which received no additional nitrogen. The yield on the velvet bean plat, however, exceeded that on the check plat by 7.5 bushels or 40 per cent. In 1901, corn was again grown, but unfortunately there is no record of a check plat that year. However, the corn on the velvet beans plowed under in 1898 and preceded by two other hoed crops outyielded the corn on the velvet bean stubble plat by 59 per cent. It is evident that the residual effect lasted, in this case, for three years. In another case, the same station calculated that, when cowpeas were turned under and were followed by three harvested crops, the financial returns were $42.96 per acre more than on similar land on which no legume had been grown.

At the Alabama Canebrake Station, bur clover and crimson clover were turned under in 1907 and cotton was grown in 1907, 1908 and 1909. Another plat received annual applications of 200 pounds cotton-seed meal and 200 pounds acid phosphate per acre, while the plats on which bur and crimson clover had been turned under received no fertilizers. The effect of the green manure was evident through the crop of 1909 as shown in Table LVII.

TABLE LVII
POUNDS OF SEED COTTON PER ACRE TREATMENT

	1907	1908	1909	Total
200 pounds cotton seed meal and 200 pounds acid phosphate per acre, annually	800	840	1008	2648
Bur clover turned under	960	860	1020	2842
Crimson clover turned under	944	960	952	2856
Check	784	744	828	2356

The fact that the residual effect has a distinct value must be borne in mind when considering whether it pays to turn under a green-manure crop. The Arkansas Station studied the residual effect of cowpeas turned under as against cowpea stubble, on wheat grown for four successive years after the cowpeas. In the last year the wheat yields were, check plat, 10 bushels, cowpea stubble plat, 11 bushels, and cowpeas turned under 12.8 bushels. The cowpea stubble gave the best increase the first wheat year, while the benefit from the whole plant was most marked the second year and was decidedly noticeable the third and fourth years. On two other plats, cowpeas were planted after wheat each year after 1899 and the yield on these plats increased each year, reaching an average of 17.2 bushels in 1902.

In the Canadian work, the residual effect was very marked. At the Central Experimental Farms, clover was grown in 1900 on some plats and was turned under in 1901, and crops grown in 1902, and 1903 with results shown in Table LVIII.

TABLE LVIII
YIELDS DURING THREE YEARS ON LAND WITH AND WITHOUT RED CLOVER
(Central Experimental Farms, Canada)

Previous Crop, 1900	Fodder Corn, 1901	Oats, 1902	Potatoes, 1903	Carrots, 1903	Sugar Beets. 1903
	Tons	Bushels	Bushels	Tons	Tons
Clover	25.80	70.59	195.33		
No clover	20.08	58.82	175.33		
Clover	27.22	70.59		31.48	
No clover	15.40	47.06		20.32	
Clover	27.88	75.29			22.30
No clover	19.64	51.77			8.60

The residual effect here is marked on every crop used.

While in the Canadian experiments the good effect of the green manure was experienced the first year, it is no uncommon thing for the turning under of a heavy green-manure crop to have a depressing effect on yields during the first year. There is reason to believe that, in such cases, benefit will be derived by the next following and possibly by more than one succeeding crop. Garner and associates have also noted the residual effect of legumes turned under and say, "An outstanding feature is the large increase in the yields of oats after tobacco and potatoes resulting from the residual effects of the legumes. In some years these yields have exceeded 80 bushels per acre." Evidence of the residual effect of a green manure is abundant in German literature. Lemmerman [165] grew rye after beets on plats green manured with Serradella.

The check plat yielded 16.8 bushels per acre, while that of the second year after green manure yielded 19 bushels per acre. The residual effect of green manures turned under for sugar cane was found by Khan to be marked. In a report on the plats green manured, three and four years previously, he says "from average outturn, as shown in statement 12, it is obvious that in the fourth year the beneficial effects of 240 maunds of bhang *(Cannabis sativa)* begin to cease, but higher applications, i.e., 480 and 720 maunds per acre, still retained their beneficial effects, and will probably continue for a few more years to come. In the three-year old plats the beneficial effect is again this year clearly marked." Such residual effect as observed is probably due to delayed decomposition rather than to the non-utilization by the first crop of the nitrates formed, since the latter, if produced in excess, are more likely to be leached out of the soil than to remain for another crop. Delayed decomposition, on the other hand, would furnish nitrates for each crop in turn as decomposition progressed.

That a part of the residual effect may be due to a transformation of the nitrogen made available by early decay into organic nitrogen of the bacterial bodies, and that this may later become available may be inferred from many of the experiments on the effect of straw. Hiltner and Peters turned under straw with and without green manure and noted the first year a depressing effect on crop yields where straw had been used and this depressing effect was confined to the non-leguminous crop, none being observed when lupines followed the application of straw. The second year, however, oats and buckwheat grown on plats to which straw had been added showed marked increases, indicating that nitrates had become available. When soil microörganisms are offered a surplus of energy material, they will consume the available soil nitrogen to the detriment of the next crop and Hiltner and Peters suggest that, where very readily decomposing green manures are turned under the addition of some straw may tend to conserve nitrates for a future crop. How far such a course would be practicable in order to secure an increased residual effect can not be stated with the information available. This is one of the many problems connected with green manuring that requires further research.

SUMMARY

The practice of green manuring has been shown to increase the yields of corn, small grain, cotton, beets, potatoes, sugar cane, and to be successful in tobacco culture in the tropics, though good results have not always been secured in tobacco culture in the United States. The failure of a green-manure crop to increase yields is not uncommon, but such bad results are believed to be due to special conditions, many of which may be corrected with increasing knowledge.

The best increases in yields are commonly secured with hoed crops, such as corn, and it is for these that green manures are especially to be recommended in the United States. The use of green manures has been attended with good results in the tropics, especially in the case of rice, but attention to the conditions under which the green manure is used is essential to success. The results secured from the use of a green-manure crop in permanent plantations in the tropics can not often be expressed in figures, but some examples are given in Chapter XIII.

There is a marked residual effect from green-manure crops and the value of this residual effect must be included in considering the profits from green manuring.

CHAPTER XI

CROPS USED FOR GREEN MANURING

MANY crops have been used for green manuring, the choice in each case depending on climatic conditions, the cropping system practiced, availability of seed and other factors including local habits and prejudices. As a rule, legume crops are used more commonly than non-legumes, although in the United States there are perhaps few crops used more generally for this purpose than rye. Whenever possible, a legume should of course be used, since besides the other benefits to be derived from growing a green manure the legume will add nitrogen to the soil. In this chapter the principal crops used for green manuring will be discussed and mention will be made of a number of minor crops, or such, as have been given promise but are not yet in general use.

The Principal Leguminous Green-manure Crops.—There are in the United States 17 leguminous crops that are more or less extensively grown as forage or as green-manure crops and a number of minor ones sometimes used, especially for green manuring. In Europe, other legumes are used, while in the tropics the number of possible green-manure legumes is large. In the approximate order of their importance as forage in the United States the legumes used in this country are: red clover, alfalfa, alsike clover, sweet clovers, cowpeas, soybeans, white clover, peanuts, velvet beans, crimson clover, field peas, vetch, Japan clover, bur clover, beggar weed and kudzu. Of these, white clover, Japan clover and kudzu are seldom, if ever, used as distinctly green-manure crops, though white clover and Japan clover do play a large part in soil improvement. White clover in the North and Japan clover in the South are almost everywhere present in pastures and there is no doubt that they play a significant part in maintaining the nitrogen content of the soil. Kudzu is used as a cover crop in pecan orchards but not as a special green-manure crop. All the others mentioned have been used, are used, or can be used as special green-manure crops and besides these, mention must be made of fenugreek, horse beans, lentils, Tangier pea, sweet peas, beans and berseem, all of which have been used to a limited extent as green-manure crops in California and the Southwest.

In Germany the lupine plays by far the most important part in green manuring on the sandy lands; it is also used on similar lands in England, in the Netherlands, in Denmark, and is in general use in the south of France and in Italy. Serradella is of some importance on the better lands in Germany, but is not much used elsewhere; in the United States neither of these crops has been successful. On the better lands in England, in Germany and in the United States, red clover in the rotation is largely depended on to keep up the productivity of the soil with other clovers and in Germany, black medic, playing minor parts. In England, with the exception of lupines, non-legumes are most commonly used as catch crop green manures. In the tropics very many legumes have been used for green manuring, a few as annuals turned under in place but a larger number as permanent plantings or from which the leaves and twigs are cut and carried for use to another field. The most important of the legumes used for green manuring with annual cultures in the tropics are *Crotalaria juncea, Sesbania aculeata,* and *Dolichos uniflorus,* though several other species, especially *Phaseolus mungo,* have been used to a lesser extent. In

China and in Japan, *Astragalus sinicus* is commonly used as a green manure for rice. Of the non-legumes, rye and other small grains, and buckwheat are extensively used in the United States, as well as in Europe for cover and green-manuring crops, while in the United States, corn and sorghum have also been used, especially in plantings with cowpeas. Members of the mustard family are among the most commonly used green-manure crops in England and are not infrequently used in Germany; in the United States the use of these crops is less common, though cow-horn turnips are highly regarded in some sections. Of other non-legumes, Mexican clover, a member of the coffee family, serves as a soil-improving crop in the extreme southern part of the United States, though not planted for this purpose, and a composite, *Vernonia cinerea,* is said to be used in the Central Provinces of India.

RED CLOVER (*Trifolium pratense*)

Red clover, Fig. 40, is a native of Northern Asia and of Europe, but in its wild form is not used except as an ingredient of natural pastures. There is no record of its use by the Romans, though clovers probably of several species did form a part in the natural hay mixtures. Red clover first appears as a cultivated plant in the sixteenth century, when it was used in Italy and Spain and from there carried to Flanders, where its good qualities were soon recognized. From the low countries, red clover was taken to England and later came into use in Germany, while the early English settlers are known to have carried seed with them to America. Wherever red clover has become established, it has, because of its marked soil-improving properties, become the cornerstone of the rotation system on the better types of soil. Being primarily a plant of northern regions, it does not thrive under conditions of high temperatures, and so has never become of much importance in the southern part of the United States.

Red clover is a biennial, though in every population there will be found a number of perennial plants. Agriculturally, however, it is usually treated as a biennial. During the first season of growth, the plant remains in the rosette form or sends up flowering stems, depending on when the seed was sown and the nature of the season or on the variety. In the second spring few to many flowering stems are sent up from the crown and these stems are more or less branched, each branch being terminated by a flower head bearing pale lavender to rose-colored flowers. The first growth commonly blooms during June and is cut for hay, after which a second growth makes its appearance and blooms in late July or early August. This second growth may be allowed to mature and a seed crop taken, or it may be turned under for soil improvement either that fall or in the following spring to serve as a green manure for corn.

By far the larger part of the red clover seeding in the United States is laid down with timothy, in which case the field is commonly allowed to remain several years, during which the red clover gradually disappears and, when the sod is finally turned, the organic matter consists almost wholly of grass. For this reason, it is not possible to estimate how extensively red clover helps in maintaining soil productivity, but the fact that the yields of other crops are high wherever red clover is an important crop in the rotation may be taken as a measure of its value. Red clover is also not infrequently used as a green-manure crop and, when used in this way, increased yields of grain or potatoes have always followed. While the value of red clover in agriculture is based on its ability to fill the dual role

FIG. 40.—A Red Clover Plant. (U. S. Department of Agriculture.)

of forage and soil improving crop, there seems good reason to believe that in some way not yet understood the decay of red clover exerts a beneficent influence beyond that exerted by the decay of other legumes. Without exception, the turning under of red clover has been beneficial, while in the case of other legumes failures sometimes follow. The percentage of total fertilizer ingredients found in the roots and stubble of red clover is larger than that in most other legumes, but this fact does not satisfactorily account for the extraordinary effect sometimes observed when red clover is turned under. Recently Page,[227] in a study of green manures for turnips on light soil, found that red clover was relatively more effective than any other crop tested. The following table has been prepared from data given by Page and shows that, although the amount of growth made by the red clover was less than that made by some other legumes, the organic matter in the red clover was much better utilized by the turnip than was that in vetch or in crimson clover.

TABLE LIX

AMOUNT OF ORGANIC MATTER AND OF NITROGEN IN VARIOUS LEGUMES TURNED INTO THE SOIL AND YIELDS OF TURNIP PRODUCED

	Weight, Green Turned under. Tons per Acre	Nitrogen Buried. Pounds per Acre	Yield of Turnip Roots. Tons per Acre	Ratio of Increase in Turnips to Ash Free Organic Matter Buried
Red clover	3.9	67	9.3	19.0
Crimson clover	17.0	182	10.5	7.1
Vetch	8.6	112	9.7	13.2

Though the weight of red clover buried was less than half that of vetch and the nitrogen in this material was almost twice as much in the vetch as in the red clover, the yield of turnips was nearly as large after red clover as after vetch. Not enough definite studies of this sort have been made to warrant conclusions, but the fact that red clover has been found to be the best source of organic matter for tobacco and the uniformly good results that everywhere follow the use of this legume, together with such data as given in Table LIX, warrant the suggestion that in the decomposition of red clover substances are formed that are more readily utilized by growing plants than is the case in the decomposition of other organic matter.

White [328] determined the quantity of nitrates produced as a result of turning under various legumes and non-legumes. Equal quantities of dry matter were used in each case, and the percentage of nitrogen in the plants as well as the quantity of nitrates produced was carefully determined. Red clover had the lowest percentage of nitrogen of six legumes used, but in decay the clover gave rise to considerably larger amounts of nitrates than

FIG. 41.—Mammoth red clover, an excellent green-manure plant.
(U. S. Department of Agriculture.)

were formed from the decay of the other legumes. White says ". . . red clover had, among the legumes the least nitrogen and by no means the most alkaline ash. These properties were, therefore, not the factors that determined the respective rates and degrees of nitrification."

While no attempt is made here to offer an explanation of this apparently unique value of red clover as a soil improver, attention is called to the fact that the entire agricultural history of this plant is in harmony with the experimental data. Wherever red clover has succeeded, there the following crops have benefited from the growth of the clover.

Mammoth Red Clover is a variety of red clover distinguished by its large, coarse, very hairy stems, and the fact that it puts forth flower stems but once a year, Fig. 41. It is largely used for soil improvement and because of greater mass of material produced, lends itself well to this purpose. The English single-cut clover resembles the American mammoth only in the fact that flower stems are produced but once a year, but is in other respects very different, being smaller, less coarse, and nearly smooth.

Seeding Red Clover.—Red clover is commonly seeded on winter grain or with spring grain, but it has been shown that, where clover anthracnose is prevalent, a stand can be secured more often by seeding in August than by spring seeding. In August seeding the young plants are not as likely to be attacked and killed by the disease. The use of an anthracnose-resistant strain is of special importance from a soil-improvement standpoint since, where anthracnose is prevalent, the second growth is frequently destroyed so that nothing is left for turning under. There is reason to believe that the prevalence of this disease has contributed not a little to the decline of red-clover culture in certain sections with a resulting decline in soil productivity. Red, alsike and white clovers have been so commonly grown in the United States that artificial inoculation is rarely necessary but they must, of course, be well noduled to produce a satisfactory growth and to add nitrogen to the soil.

Turning under Red Clover.—The time at which a red-clover stand should be turned under will depend on the crop that is to follow and on the farm management requirements. When a second growth of red clover is to be turned under for winter grain, the clover field should be plowed in July so as to leave time for decay and for the soil to settle. When the clover, as is more often the case, is to be followed by corn the field may be plowed in late fall or in early spring as is most convenient. Fall plowing of a ripe crop of clover is sometimes practiced, even on light land and with good results. As a rule, there is little to be gained by spring plowing, since the time is too short for the clover to make any material growth in spring unless silage or fodder corn is to be planted, in which case plowing can be put off longer than when a standard corn crop is to follow.

ALFALFA (*Medicago sativa*)

Being a perennial and an especially valuable plant for forage, alfalfa is seldom used purely as a green-manure crop, though its use as such is not unknown. It does, however, in certain sections play a considerable part in green manuring, since an entire year's growth is sometimes sacrificed for its value as a fertilizer for potatoes. Alfalfa produces many upright stems from a crown and these stems are clothed with shorter branches and leaves, each of which consists of three leaflets. The flowers are bluish purple, or in the hybrid forms (Grimm, Cossack, Canadian variegated) often greenish or yellowish and are borne on short racemes. The root system is large and well branched and penetrates deep into the subsoil provided this is well drained. Alfalfa roots will not penetrate a thick hardpan and the plant will not thrive in distinctly acid or poorly drained soils.

Alfalfa not only requires lime in the soil, but is dependent on inoculation for satisfactory growth. In the western part of the United States, the inoculating organism appears to be everywhere present, but east of the Mississippi River inoculation must be provided when alfalfa is grown on land on which it, sweet clover, bur clover, or yellow trefoil has never before been grown. The proportion of root to tops is large, but is difficult to determine accurately because alfalfa produces several crops of tops in a season. In any event there is a larger proportion of root to top in alfalfa than in any other legume, except possibly red clover, and some students have found the proportion of root to top to be larger in alfalfa than in red clover. This large proportion of roots and the high nitrogen content of both tops and roots makes even an alfalfa sod and stubble of great value as a preparation for a hoed crop. When an entire season's growth is turned under, 150 to 200 pounds of nitrogen per acre may be supplied for the use of the following crop.

Seeding Alfalfa.—Alfalfa is best seeded on a carefully prepared, well-compacted seed bed. In the eastern United States, July is the best time for seeding and the field intended for alfalfa should be worked in the early part of the season to keep down weeds. Young alfalfa plants grow slowly and are easily smothered by weeds. In some sections of the southwest, it has been found advisable to turn under a crop of cowpeas as preparation for alfalfa, as better stands were secured in that way.

Turning under Alfalfa.—As a special green-manure crop, alfalfa is known to be used only to prepare the land for potatoes. In this case, the entire growth of a season, or sometimes only the second growth is left on the land and the whole turned under in spring. The results are said to warrant the sacrifice of the hay crop.

ALSIKE CLOVER (*Trifolium hybridum*)

This plant is a perennial in regions where it is at home, but in the southern part of the clover belt in the United States, it seldom survives more than one year and is commonly treated as a biennial everywhere. It is a native of northern Europe and is used in the Scandinavian countries and in Germany, but is not much used in southern Europe. It is also known as Swedish and as hybrid clover, the latter name being used because of a mistaken notion that Alsike is a cross between white and red clover. Many smooth stalks come from a crown and they bear smooth leaves, each consisting of three leaflets, and heads of pink or white flowers. As the flowers age, they bend back and hang down. Under favorable conditions, the stalks may grow 3 to 5 feet in length, but on drier soil they are usually about 18 inches long. The main stalk keeps on growing while flower-bearing branches arise from the axils of the lower leaves and so the oldest heads are below, the younger ones above.

Alsike clover prefers a cool climate and a moist soil and in the northernmost part of its range or on especially rich moist soil in the corn belt, it has been known to make two crops a season; as a rule, however, only one crop can be expected. In spite of its being most at home on moist lands, it will catch on drier and more sour soil than red clover and also on the poorly drained parts of fields and it is consequently much used to mix with red clover in order to insure a more uniform stand over an entire field. Alsike clover will also endure more wet than red clover and in experiments conducted at the U. S. Department of Agriculture has been grown for a year in closed tanks in which the water was kept constantly at a level of 3 to 4 inches above the surface of the soil; under these conditions growth was good.

While alsike clover can be depended on for one crop only, this is usually heavier than the first crop of red clover. Since alsike clover is usually seeded in mixtures, it does not often serve as a green-manure crop, except through what second growth may be turned under, but it has been known to be used purely as a green-manure crop, heavy pure stands of alsike having been turned under for the following crop of corn. It is also sometimes used as a cover and green-manure crop in orchards.

In nitrogen content, alsike clover is fully equal to red clover, but its root system is not quite as extensive and deep rooting. On the whole, it should fill nearly the same place in soil improvement as red clover, at least when an entire crop is turned under for green manure.

CRIMSON CLOVER (*Trifolium incarnatum*)

Crimson clover, Fig. 42, is a winter annual and is an important crop along the Atlantic Coast from New Jersey southward and in many parts of the cotton belt. It is a native of Europe, where it is cultivated as a forage and green-manuring crop in Italy, France, Germany, Austria and Great Britain. Its culture is perhaps most extensive in central France whence large quantities of seed are annually exported to the United States. It is most commonly known in the United States as crimson clover, but the names scarlet clover, German, French, Italian, incarnate and annual clover have all been applied to it. During the fall and winter, the plant is a rosette of basal leaves, but early in spring many stems arise from the crown and each stem is terminated by a long head of scarlet or crimson flowers. In the latitude of Washington, the plants are in full bloom during the last half of May. While the root system of crimson clover is extensive, it does not compare favorably in this respect with red clover, only about 25 per cent of the entire plant being in the root as against about 34 per cent for red clover, but the total

quantity of nitrogen turned under per ton of crimson clover is not much less than for red clover. The peculiar value of crimson clover as a green-manure crop lies in its ability to make a fair growth in fall and a very rapid growth early in spring, so that it has commonly attained maximum development by the time it must be turned under for corn. In the South, it is necessary to turn crimson clover under before reaching full development if it is to be followed by cotton, but even then it can be so handled by the ball system that a seed crop can be taken after the cotton is up.

Varieties.—There are several varieties of crimson clover differing mainly in earliness or lateness and there is a white blooming variety. None of these special varieties is in common use in the United States, though by

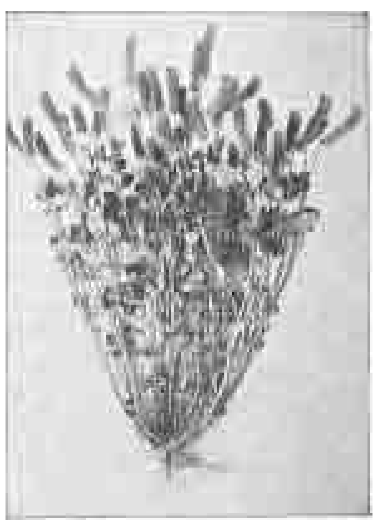

FIG. 42.—Crimson clover, one of the best winter green-manure crops for the Atlantic seaboard.
(U. S. Department of Agriculture).

reason of earliness or lateness some of them have value in extending the time of maturity of the crop.

Crimson clover is limited in its range by the fact that it is not resistant to extreme cold or to extreme heat. It requires cool weather for its best development and hence can be grown successfully only where the winters are not too severe or where the summers are cool.

Soils and Fertilizers.—Crimson clover can be grown on almost any fairly good soil, but it is not a crop for extremely poor soils. On such

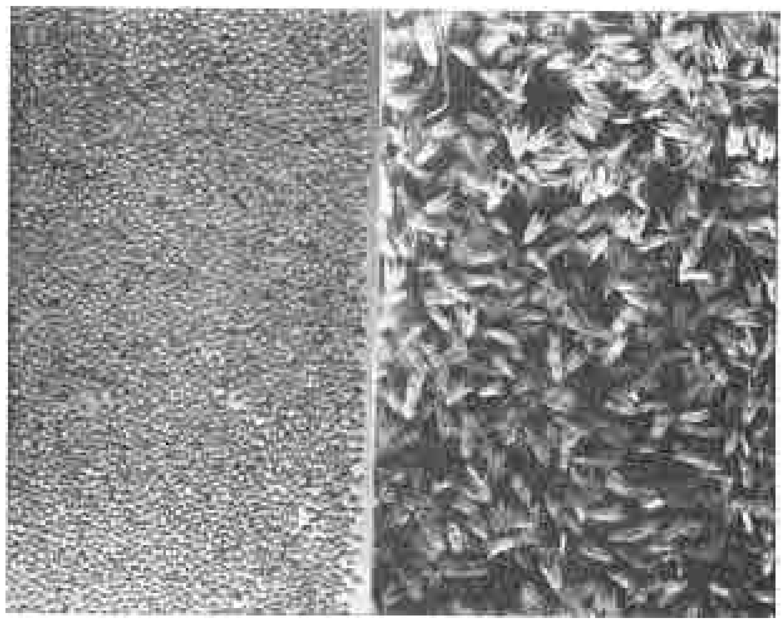

FIG. 43-—Crimson clover seed, at left hulled, at right, unhulled. The unhulled seed is harder to handle but gives best results.
(U. S. Department of Agriculture.)

soils one or more crops of cowpeas should be turned under so as to add humus to the soil before a regular rotation including crimson clover as a winter green-manure crop is started. When crimson clover follows a crop that has been well-fertilized, no extra fertilizer will be needed for the clover, but otherwise it will pay to use phosphates or potash or both according to the requirements of the particular soil. On sandy soils, 150 to 200 pounds of acid phosphate and half as much potash and on clays 200 to 300 pounds of acid phosphate will materially benefit the clover.

Seeding Crimson Clover.—Crimson clover should be seeded in the United States in the period from August 15 to October 1, though south of Virginia it may be seeded as late as November 1. A good general rule is to seed about sixty days before the first killing frost so that the plants may become well established. Seeding may be done after grain harvest or in the last working of the corn, after early potatoes or at the last working of tomatoes or similar crops. When to be seeded after small grain the stubble should be plowed immediately or disked so as to conserve the moisture, since lack of moisture is the most common cause of the failure to get a stand of crimson clover, especially so in the South, where, in some sections, the late summer and early fall months are sometimes dry.

Seed.—The risk of losing a stand may be avoided to some extent by using unhulled seed. The seed sold by the trade is almost always hulled and has the advantage of cheapness and convenience of handling. Many growers, however, save their own seed, using various devices or even stripping the seed by hand. It has been found by experience, as well as by experiment, that natural unhulled seed will give a better stand than hulled or clean seed and it is believed that this fact is to a certain extent correlated with moisture conditions, but no exact experiments have been made to test this. About two times the quantity of unhulled seed by weight as of hulled seed should be used, Fig. 43.

BERSEEM (*T. alexandrinum*)

This annual clover, also known as Egyptian clover, is an important forage crop in the Nile Valley and in India, but has not been found useful in the United States except in the Imperial Valley of California and in the Yuma Valley. Here it does well under irrigation and is sometimes used for green manure. The plant has a slender weak stem and white flowers borne in heads much like red clover but longer. When conditions are favorable it grows rapidly and produces a large mass of succulent material for turning under. It will not withstand severe cold and does not thrive in hot weather. It is, therefore, a winter crop in sections where severe freezes do not occur.

SWEET CLOVERS (*Melilotus spp.*)

Some species of *Melilotus* are among the most valuable soil-improving plants known and the genus as a whole will without doubt take first rank in temperate regions when considered purely as a green-manure crop. Three species and one variety are used in the United States and some of these have a much wider range. Of the three species, two, *M. alba* and *M. officinalis,* are biennial and may be discussed together as they differ little in their agricultural uses and adaptations. The third, *M. indica,* is an annual and occupies quite a different range and field of usefulness from that of the biennials. The variety, *M. alba annua* is an annual variety of the biennial white sweet clover

White Sweet Clover (*Melilotus alba*).—This plant, also called *Bokhara* clover or Bokhara melilot, is a native of Europe and Asia as far east as Thibet and was introduced into the United States, probably at some time early in the eighteenth century. Its value was not appreciated, however, and for many years it was condemned by state laws as one of the dangerous weeds to be destroyed like thistles and burdocks. Its first recorded use as a soil improver was on the abandoned tobacco

fields of Pendleton and Harrison counties in Kentucky. These limestone soils were cropped out and many of the farms were abandoned; washing of the slopes became serious and the land was practically useless. As the farmer moved out the wild sweet clover moved in, covered and protected the surface, opened the subsoil, and in dying left new stores of humus and nitrogen in the impoverished surface soil. One generation of sweet clover followed another, until someone discovered that the once barren soil was rich again. During the past twenty years farmers have come to understand sweet clover better and an appreciation of its good qualities is steadily increasing. Not only is it of high value as a soil-improving crop, but it is one of the best pasture crops for all limestone or well-limed soils in North America. In this book, however, sweet clover will be considered as a green manure-crop only.

The Yellow Sweet Clover (*M. officinalis*) differs from the white in color of flowers, finer stems and sometimes in more prostrate habit. It is not much used in the eastern United States, but is more common in

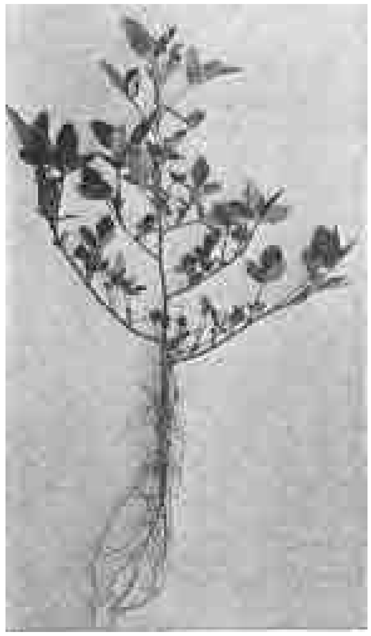

FIG. 44.—A white sweet clover plant, nine weeks old. Note branched single stem and strong root.
(U. S. Department of Agriculture.)

the Northern Great Plains and Rocky Mountain states. With these differences, the comments made on the white will apply equally to the yellow sweet clover.

Both white and yellow sweet clovers are biennial, the growth during the season of seeding depending on date of seeding, fertility of the soil, inoculation, and climatic conditions, Fig. 44. Whatever the first season's growth, buds are formed on the crown of the plant before winter sets in and from these buds new growth is started the following spring, Fig. 45. During the first season but one stem is formed, which may or may not branch and bears three parted leaves; the middle section of each leaf is borne on a short separate stalk; young sweet clover looks very much like alfalfa. In the second season several to many strong stalks are sent up very early in spring, the number depending on the number of crown buds previously formed and these stalks branch freely, Fig. 46. Except in rare cases, no flowers are produced the first season, but during June of the second year numerous flowering branches appear bearing long racemes of white or yellow flowers, according to the species. When in full bloom, white sweet clover may be from 3 to 10 feet high, depending on the variety and soil, and is then a much-branched, woody plant. After maturing seed the plant dies; no perennial variety has been found, though such a one would have obvious advantages as a forage crop.

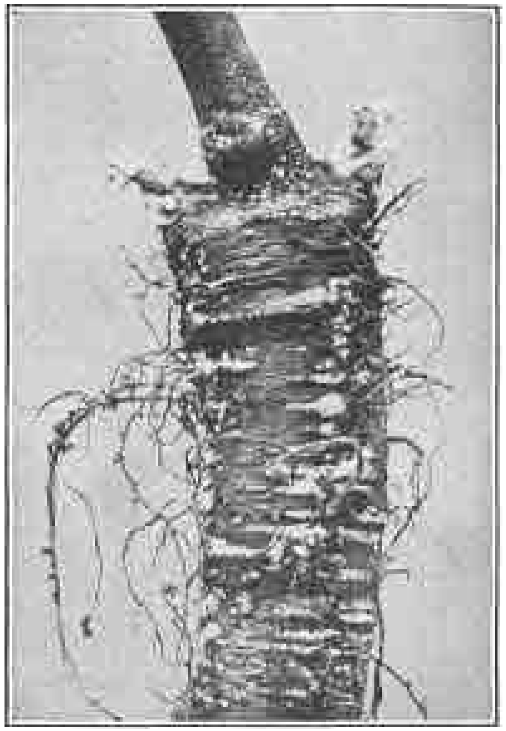

FIG. 45.—Upper end of a white sweet clover root showing resting buds on the crown. (U. S. Department of Agriculture.)

Roots.—The main root of the biennial sweet clover is a strong tapering tap root capable of penetrating rather stiff subsoils, and is usually more or less branched. Toward the end of the first season's growth, the roots are filled with reserve plant food materials on which the clover draws for its rapid spring growth. The proportion of root to top varies widely, depending largely on the stage of development of the plant. The most complete study of the relative amounts of tops and roots in white sweet clover has been made by Whiting and Richmond,[337] who examined the roots from October 15 of one year to October 1 of the next. The relative proportions of tops and roots as reported by Whiting and Richmond are given in the table LX.

It is notable that in late fall of the first year and in early spring of the second the largest part of the total weight of the plant is in the root, but that this relation rapidly changes as the new top grows. In considering the use of biennial sweet clover as a green manure, the large proportion of the total weight that is in the roots in early spring is especially significant, since the best time to turn under sweet clover is in spring to precede a hoed crop. Whiting further found that 86 per cent of the nitrogen in the roots of sweet clover was in water-soluble form and hence readily available to the succeeding crop. The potassium in sweet-clover tops is said to be very soluble and 37 per cent of the nitrogen in the tops is soluble in water.

In a similar study, Snider and Hein also found that from the beginning of growth in April to the first of May the greater portion of the total dry matter of the crop was in the roots, which were found to penetrate to a depth of 40 inches. In one series of samples, the nitrogen found in the crop during November and December aggregated 283 pounds per acre and during March and April of the following season 228 pounds per acre. This

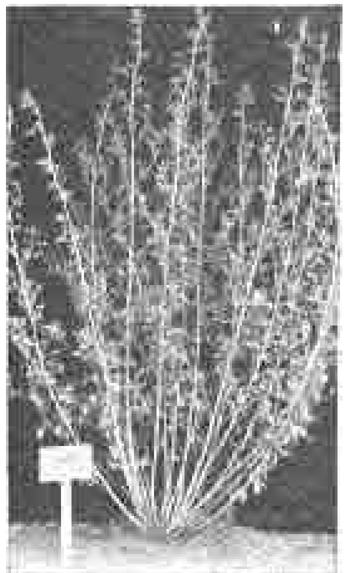

FIG. 46.—A single plant of second-season white sweet clover just before bloom. Note the numerous strong stems.
(U. S. Department of Agriculture.)

TABLE LX
RELATIVE WEIGHTS OF TOPS AND ROOTS IN WHITE SWEET CLOVER AT DIFFERENT DATES; WATER-FREE BASIS*
(Dug at Urbana, Illinois)

Date		Per Cent of Whole Plant	Date of		Per Cent Whole Plant
October 15, 1919	tops	42	July 3, 1920	tops	86
	roots	58		roots	14
October 25, 1919	tops	37	July 17, 1920	tops	82
	roots	63		roots	18
May 10, 1920	tops	45	August 1, 1920	tops	78
	roots	55		roots	22
May 20, 1920	tops	48	August 14, 1920	tops	70
	roots	52		roots	30
June 3, 1920	tops	81	August 28, 1920	tops	73
	roots	39		roots	27
June 19, 1920	tops	80	September 11, 1920	tops	76
	roots	20		roots	24
			October 1, 1920	tops	79
				roots	21

* Data from Soil Science, 22: 86. By permission of Williams and Wilkins.

large amount of nitrogen in living tissue is not subject to loss as would be the case with nitrates developed in fall and left in the ground, but is made available rapidly when the crop is turned under in spring.

These studies showed further that not until the end of May did the total dry matter, tops and roots, exceed that present soon after growth began in April, and that consequently no serious loss is involved in turning under the crop before the middle of May. In some cases even larger proportions of root growth than cited above have been reported. "On the Spring Valley field, (Ill.) for instance, the root growth of sweet clover from March 24 to April 19 made up 97.5 per cent of the weight of the plant, as an average of two years, 1922 and 1923. From April 20 to May 14 the root growth was 62.2 per cent of the plant, and from May 17 to June 13 the root growth was 30.8 per cent of the plant."[11]

Method of Using Sweet Clover as Green Manure.—As a green manure, biennial sweet clover is either a companion crop or a catch crop green manure. In either case the best and most common practice is to allow the clover to stand over winter and to turn it under after growth has commenced in spring. Sweet clover does not, therefore, occupy a field for the entire season to the exclusion of a money crop, consequently a cash crop may be grown every year. Sweet clover can, of course, be seeded alone in spring and allowed to occupy the ground an entire season in which case a hay crop may be taken or a large amount of pasture may be secured; in no case is it necessary to devote a cropping season to the green-manure crop alone, and even when used as a companion crop, hay or pasture can often be secured the first season. The cost of the sweet clover green manure is, therefore, confined to the cost of the seed and even this may be returned in pasture or hay.

Soils and Climate for Sweet Clover.—Sweet clover will thrive on a great variety of soils, provided these are reasonably well supplied with lime, Fig. 47. While instances are known where sweet clover has done well on sandy soils showing by the Veitch method a lime requirement of 1000 or 1200 pounds per acre, these do not affect the general rule. It is not known why sweet clover will sometimes thrive on somewhat acid soils though the physical texture probably has something to do with the case, but much experience and many experiments have shown that it is unsafe to sow sweet clover on sour soil. When, however, a soil contains available lime and the sweet clover is inoculated, it will thrive on the poorest of soils, being able to secure phosphates and potash from soils on which corn or red clover would make almost no growth whatever. "Sweet clover thrives on the adobe and granite soils of the Pacific Coast; upon the gumbo, hardpan, prairie and sandy soils of the western north-central states; and upon the heavy clay, loam, limestone, and sandy soils of the South and East."[41] The plants thrive on newly exposed heavy clay soils and on the "white" soils of southern Illinois after these have been limed.

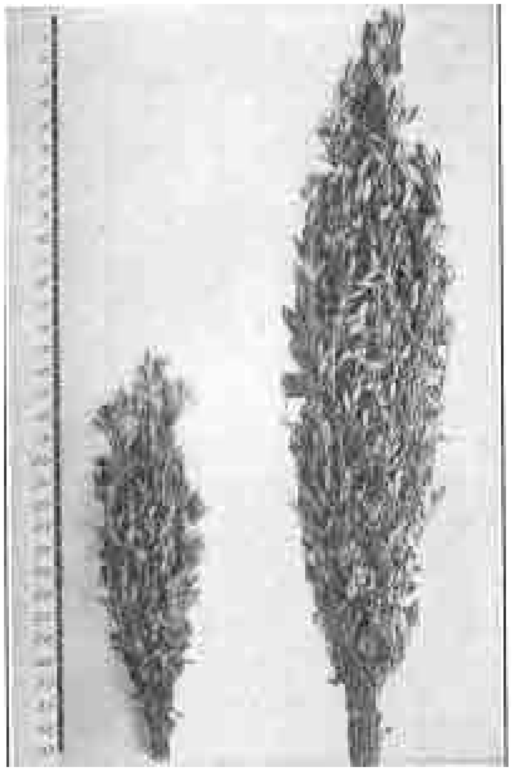

Fig. 47. Sweet clover needs lime. Plants at the right from limed, at left from unlimed soil, equal areas.
(U.S., Department of Agriculture.)

Bauer studied the ability of various plants to grow when raw rock phosphate and ground feldspar were the only sources of phosphorus and potash. Placing the growth made on acid phosphate and on soluble potash at 100 in each case the relative growth made on rock phosphate and on feldspar was found to be as follows:

	On Raw Rock	On Feldspar
Red clover	33.3	
Wheat	34.4	
Oats	41.5	107.6
Corn	41.9	45.2
Timothy	45.2	
Soybeans	47.7	
Rape	54.1	
Alfalfa	62.3	
Rye	66.9	
Buckwheat	72.1	23.3
Redtop	72.3	
Sorrel	82.9	
Sweet clover	83.0	106.5

This ability of sweet clover to utilize the insoluble minerals makes it an ideal green-manure crop for poor soils, since on the decay of the clover these minerals are made available to crops that are not so well able to use the raw rock materials.

While sweet clover prefers well-drained soils, it will do well on soils with a water table too high for alfalfa and has been found growing to a height of 7 feet on wet muck among *Juncus* and other swamp plants, as well as on the drifting sand of the dunes along Lake Michigan. It also does well on soils too alkaline for grain or alfalfa; in one case reported from Oregon a good stand of sweet clover was secured on land so heavily impregnated with black alkali that only salt grass would grow on it before the sweet clover was planted. Sweet clover is not only most catholic in its choice of soils, but in its adaptability to climate as well. The northernmost parts of Alberta and Saskatchewan are not too cold nor Alabama and Mississippi too hot for the plant. The resting buds are very resistant to cold, though in the coldest parts of the North, winter killing is not unknown. In more temperate sections, there is often more winter killing than in the colder regions, because in the former heaving may be serious, especially on heavy soils. This is especially the case with late seeded sweet clover, the roots of which do not attain large size and are readily lifted out of the ground as a result of alternate freezing and thawing.

Inoculation.—Wherever the nodule organism is not present, inoculation is essential for success with sweet clover. This is especially true when sweet clover is seeded on poor soils for the purpose of soil improvement. Such soils are commonly deficient in nitrogen and without the help of the nodule bacteria the sweet clover makes but a feeble growth and is of little or no benefit to the soil, Fig. 28. Methods of inoculation have been discussed in Chapter IX.

Seed and Seeding.—Sweet clover seed in the hull has a hard seed coat, so that such seed germinates but slowly unless subject to the effect of winter. Commercial sweet clover seed is, however, commonly hulled and the percentage of hard seed present in the hulled seed varies widely, but is usually high enough to make it desirable to use scarified seed when sowing in spring. Seed is scarified by being put through a machine which rubs the seed against a rough surface, usually sandpaper, so that minute scratches are made in the seed coat. As a consequence of this scarification, moisture enters the seed more readily and germination is more prompt and uniform. Unhulled seed or seed not scarified is sometimes seeded in fall with fairly good results, but as a rule early spring seeding of scarified seed is most likely to insure a stand.

Sweet clover requires a firm seed bed and no other preparation is more important than the compacting of the seed bed. In case seeding is done on wheat, as is the most common practice, the seed bed is firm enough, but when seeding is done on plowed stubble, or on spring-plowed land, care must be taken to compact thoroughly.

When to Turn under Sweet Clover.—Sweet clover is best turned under in spring for a hoed crop to follow. When turned under about the first of May in the corn belt the tops may be from 6 to 8 inches high and the green weight of tops may furnish from 2 to 5 tons of fresh green material per acre; the amount of organic matter in the roots at this time will be fully as great. This tender material decomposes rapidly and supplies an abundance of nitrates for the growing corn, beets, or potatoes. In some sections, fall plowing is either necessary or advantageous and sweet clover may be fall plowed if a hoed crop is to follow, but there will nearly always be some volunteer sweet clover among the next season's crop, because the resting buds are not all killed by plowing. Deep fall plowing together with thorough disking in spring will reduce the trouble from the sweet clover to a minimum, but wherever spring plowing is possible this is recommended. Sweet clover should never be plowed in the fall of its first season's growth when the following crop is to be small grain, as in such a case the field will probably carry more sweet clover than grain, Fig. 48.

Annual White Sweet Clover.—This annual variety of the biennial white sweet clover known as Hubam was introduced to the general attention of agronomists by Prof. H. D. Hughes of Ames, Iowa. It differs from the parent form in failing to make resting buds on the crown and in

FIG. 48.—Sweet clover was turned under on this North Dakota field in the fall of its first year and barley seeded the following spring. The volunteer sweet clover has almost completely hidden the barley.
(North Dakota Agricultural Experiment Station.)

completing its growth and seeding the first season. The root system is not as large as that of the biennial, but where a green-manure plant is wanted for turning under for fall-seeded grain it is useful. The annual form is also being used as green manure in some orchards where a legume is wanted that will not interfere with early spring cultivation.

The place of the Hubam clover has not yet been thoroughly determined and it appears to be subject to much greater variation in quantity of growth and especially in the proportion of roots to tops than the biennial. Wilkins, in Iowa, found that during the first season the Hubam outyielded the biennial, had about the same proportion of root to total growth, 30.54 per cent, and, though the percentage of nitrogen in tops and roots was a little less, provided nearly the same amount of nitrogen per acre. On the other hand, Willard and Thatcher, in Ohio, found that "the biennial had seven times as great a weight of root in the first foot as the Hubam, besides many roots going deeper." The biennial also contained "30 times as much nitrogen per acre in the roots," as the Hubam. Arny and McGinnis [17] found that, while at the end of the first season's growth of the biennial the total weight of tops and roots was nearly the same for the annual and the biennial, the roots of the biennial made up 51.73 per cent of the total, while in the annual the roots were but 9.2 per cent of the total.

It seems probable that in the course of time the proper place for the Hubam will be found and that, while it will doubtless not compare favorably with the biennial in the amount of nitrogen fixed, it will be a useful green-manure crop wherever a quick growing legume is wanted that can safely be turned under in fall. It may also be useful to precede late potatoes in the latitude of Washington. Self-sown seed of Hubam at Arlington produced plants that made a growth of 2½ feet by the first week in June. Such a mass of succulent green matter can not fail to be a good green manure.

The Yellow Annual Melilot (*M. indica*).—This species is an annual of considerable value as a winter green-manure crop in citrus groves in

California and on the sugar-cane plantations in Louisiana. It is quite useless north of the cotton belt in the United States, since plants from spring seeding flower and produce seed when only a few inches high, but it has become an important forage and soil-improving crop on Kings Island, near Tasmania. Its use as a green-manure crop is probably more general in the United States than anywhere else.

The yellow melilot, also called sour clover, bitter clover, or where it is common in Alabama, sometimes simply melilot, and in Tasmania King Island melilot, is **a** bushy plant growing under good conditions, 2 to 3 feet high and bearing many racemes of yellow flowers. In the California citrus orchards, it has produced 12f tons of green tops per acre as an average of five years and has affected increases in the yields of corn, potatoes and sugar beets greater than those produced by turning under barley in addition to more than 1000 pounds of nitrate of soda per acre.

COWPEAS (*Vigna sinensis*)

This native of Central Africa has long been grown in the southern United States and many varieties have been developed. It is an annual hot-weather plant with large three-parted leaves, bean-like flowers and long pods, Fig. 24. Some of the varieties are twining plants and are useful for planting with corn or sorghum, others lack the twining habit and are erect plants 2 feet or more in height. The varieties are most readily distinguished by the color and size of seed, although they also differ in habit, length of growing period, yield of seed, and disease resistance.

The cowpea is without doubt the most important summer green-manure and catch crop in the United States. Its culture in the South is widespread and as a catch crop or summer orchard green-manure crop it is used far north of the area in which it can be expected to mature. The cowpea is really a bean and as such is extremely sensitive to cold, being damaged by the slightest frost. While this fact limits its use somewhat, the ability of the cowpea to make some growth on the poorest land and to make a good growth in a few weeks in hot weather makes it especially valuable as a restorer of worn-out soils and as a catch crop. Cowpeas will grow on land on which crimson clover will not grow at all and when adequately fertilized one crop of cowpeas on such land will add enough humus to the soil to make the culture of crimson clover possible.

Roots.—The root system of the cowpea is fairly extensive for an annual, going down to 4 feet or more, but the great mass of the roots is in the upper 6 to 12 inches of the soil. Less than 15 per cent of the total plant weight is in the root, but the turning under of roots and stubble only, commonly results in increased yields of the following crop; part of this good effect is due to the favorable physical condition in which a crop of cowpeas leaves the soil. The roots are commonly well-supplied with nodules and soil inoculation is not usually necessary. Most of the experiments on green manuring in the United States have been conducted with cowpeas as the green-manure crop and increased yields of the succeeding crop have usually resulted.

Seeding Cowpeas for Green Manure.—When intended for use as a green manure, cowpeas are seeded with corn at the last working or are disked in on the stubble of a grain crop, but they are also sown as a main crop in orchard green manuring or on very poor land. The practice of sowing with corn at corn-planting time is of doubtful value as the cowpeas have usually reduced the yield of the corn with which they were seeded, a result apparently of insufficient moisture for both corn and cowpeas.

Seeded at the last working of corn, cowpeas still have plenty of time to make a heavy growth and this is also true of seeding on grain stubble when moisture conditions are favorable, since in sixty days of frost-free weather cowpeas will produce a large amount of organic matter for turning under. When used as a main crop green manure the seed should not be sown until the ground is thoroughly warm. Nothing is to be gained by extra early sowing and if the ground is cold and wet the seed may rot or the plants that do come may be feeble; in orchard work, cowpeas are best sown about June 15.

Turning under Cowpeas.—Being a summer crop, cowpeas will have completed their growth by the end of the season and may be turned under in fall or the dead material may be left as a ground cover until spring. No studies have been made on the loss of organic material resulting from leaving cowpeas on the ground until spring, but such loss is probably considerable. Observation of a stand of cowpeas a few weeks after the first hard frost shows that there is little left but a mass of stems, the leaves have

FIG. 49.—Turning under cowpeas for green manure.
(U. S. Department of Agriculture.)

nearly all disappeared. At Washington,D. C, the stems even have often completely disappeared by spring. Part of the fertilizing substances in the leaves is doubtless absorbed by the soil, but Boltz has shown that when red clover is left on the surface over winter there is a large loss of organic matter and this loss is probably fully as great in the case of the cowpea. When cowpeas are turned under in the fall in the South with no winter crop to follow, there is sure to be a heavy loss of nitrogen before spring, since the cowpea is of tender texture and decays readily. Where a winter legume as crimson clover or hairy vetch can be grown and turned under in spring for a hoed crop the utilization of the nitrogen is certain to be more complete than when cowpeas are turned under for a summer crop. However, the cowpea does well on soils too poor or too sour for the successful culture of any clover and for this reason will doubtless retain its place among the important green-manure crops of the United States, Fig. 49. Cowpeas are sometimes rolled down before being turned under, Fig. 50.

Fig. 50.—Rolling down cowpeas before plowing.
(U. S. Department of Agriculture.)

SOYBEANS (*SOJA MAX*)

The soybean has been cultivated from ancient times in Japan and in China, but only in the last thirty years has it taken an important place in American agriculture. It is adapted to a much wider range of climate than the cowpea, being grown successfully even in Ontario and in Wisconsin. The soybean is an annual and in most cultivated varieties the stem is erect and somewhat branched. The flowers are small, white or purple and borne on short axillary racemes which usually have 8 to 10 flowers in a cluster. The pods vary in length according to the variety from ¾ of an inch to 3 inches, are hairy, and are borne in clusters of 3 to 5 or sometimes more. The leaves are large, three parted, and beanlike in shape and the entire plant is hairy. The nitrogen content of the soybean is high and if the whole plant is turned under the soil will be materially enriched. The root system is not quite as extensive as that of the cowpea however, and is very much less than that of the clovers. When soybeans have been grown in rotation with corn, increased yields of corn have usually followed, even though the soybeans were removed except for fallen leaves and stubble and these increases have been, in general, of about the same order of magnitude as those secured after cowpeas.

As a green manure soybeans are used as a catch crop in various parts of the United States but their use is not common, Fig. 51. Possibly their use will increase when the seed is cheaper, but at present the crop is too valuable as forage and the seed too high in price to warrant its use for soil improvement. The soybean is susceptible to the root-knot nematode and, where this pest is prevalent in the soil, it should not be planted, or resistant varieties as Laredo and Otootan should be used.

FIG. 51.—Turning under a soybean green-manure crop for oats in Kansas. (U. S. Department of Agriculture.)

Seeding and Inoculating.—Soybeans are best seeded in rows so that they can be cultivated, as they do not compete with weeds as successfully as the cowpea, and when seeded in rows a much smaller quantity of seed is needed than when the seed is sown broadcast. Artificial inoculation is always necessary when soybeans have not before been grown on a field, but when once well inoculated the soybean roots are heavily noduled and doubtless draw large amounts of nitrogen from the air, Fig. 27.

Soybeans may be used as a catch crop following wheat or oats or may be seeded in corn at the last working of the corn. They endure some frost and consequently have a longer growing season than cow-peas. Soybeans are used to some extent as catch crop green manures in China and in Japan.

VELVET BEANS (*Stizolobium deeringianum*)

The velvet bean is an annual hot-weather crop adapted to the cotton belt area in the United States and to the tropics generally. There are several species of *Stizolobium,* but *S. deeringianum* is the only one in common use in the United States and of this there are several varieties. In the Hawaiian Islands, the Lyon bean and the Mauritius bean, representing other species, are used. The varieties in the United States differ in habit and in earliness of maturity. The Florida velvet bean requires a long season to mature, is a twining plant and a vigorous grower, some of the branches reaching a length of 50 feet. Of the earlier maturing varieties derived from the Florida, the Alabama is the most widely used and differs from the Florida in ripening seed in about half the time needed by the parent variety. There is also a bush or bunch, non-twining variety, which is popular as a green-manure crop for orchards.

The flowers of the different species vary in color from white to dark purple, are 1 to 1½ inches long and are borne singly or in twos or threes in long pendant clusters. The pods of the Florida and Alabama varieties are 2 to 3 inches long and covered with a fine black pubescence, while in the

Lyon bean the woody pods are 5 to 6 inches long and covered with a fine gray pubescence.

Roots.—Velvet bean roots are somewhat fleshy and spread widely, some becoming 30 feet long, and are well supplied with large nodules, Fig. 15. The proportion of root to the entire weight of the plant is, however, small and the nitrogen content of the roots is relatively low. Studies at the Florida and the Alabama Agricultural Experiment Stations showed only about 10.5 and 13 per cent respectively of the total dry matter in the roots. As a green-manure crop, the velvet bean is especially valuable on very poor soils, since on these it will produce a larger mass of growth than any other legume, but its range in the United States is limited by the fact that it requires a long season of hot weather and hence is useful only in the South.

Seeding Velvet Beans.—The seeds of the velvet bean are large and, when planted for a green-manure crop, from ½ bushel to a bushel of seed should be used per acre and planting should be done when warm weather has set in, that is about corn-planting time. In pecan orchards, the beans are scattered on the plowed ground which is then harrowed smooth.

The great mass of viny growth produced by a good crop of velvet beans makes the job of turning them under a difficult one for the man with small tools. In the pecan orchards of southern Georgia where velvet beans are often used as green manure, the vines are first cut up by a heavy disk harrow, the first harrowing being sometimes crossed by a second. A disk plow is then used or, if a mouldboard plow must be used, a rolling coulter is attached; with such tools the crop is turned under without difficulty. When the vines are first grazed, as is the common practice, no difficulty is experienced in turning under what is left.

VETCHES (*Vicia spp.*)

The vetches in more or less common use in the United States are all annuals and are mostly grown as winter annuals, though hairy vetch, when spring seeded, is a biennial. Five species are more or less used, common vetch, hairy vetch, purple vetch, Hungarian vetch, and woolly podded vetch, but of these common and hairy are by far the most generally useful.

Common Vetch *(Vicia sativa).*—This is also known as Oregon winter vetch and as English vetch, the latter name referring to its common use in England, where it is also called tares. There are both spring and winter strains of common vetch, but in the United States only the winter strain is used as a green manure. The plant has a smooth weak stem, 3 to 5 feet long, pinnate leaves with about 7 pairs of leaflets and a terminal tendril. The flowers are violet purple, rarely white, borne in pairs and the brown pods contain 4 or 5 marbled, mottled brown or gray seeds.

As a green manure, common vetch is useful in sections where the winter temperature does not fall below 10° F., when lower temperatures occur there is more or less severe winter killing. This fact makes common vetch most generally useful on the Pacific Coast, especially in Oregon, where it is much used as a winter green-manure crop.

Seeding Common Vetch.—In western Oregon, vetch is seeded in October, though there is said to be a tendency toward earlier seeding; in southern California seeding is done in late August or in September, while in the southern states October is the best month. When seeded alone, a bushel of seed (60 pounds) is commonly used, but when conditions are favorable 40 pounds will give good results. If the surface soil is in good condition, seeding may be done broadcast and the seed harrowed in or it may be drilled, the seed being placed not more than 3 inches deep, the depth depending on the character of the land. On the Pacific Coast, artificial inoculation has been found not necessary, but when vetch is seeded in the southeastern United States on land on which no vetch has been grown the seed or the soil should be inoculated.

The yield of green matter for turning under is larger than that produced by field peas, but not as large as that produced by purple vetch. At the Southern California Agricultural Experiment Station a five-year average yield of 12 tons per acre was produced by common vetch, 9 tons by field peas and 18¼ tons by purple vetch.

Hairy Vetch *(V. villosa).*—Hairy vetch differs from common vetch botanically in having narrower, more numerous leaflets, hairy, somewhat silvery herbage and blue-violet flowers borne in one-sided clusters of about thirty on a long stalk. It has been called Russian vetch, Siberian vetch and winter vetch, but the last-mentioned name is used by European seedsmen for the winter strain of common vetch and its use for hairy vetch should be avoided. The name hairy vetch is by far the most common and distinctive. This species is very hardy, succeeding as a winter legume as far north as Michigan, New York and even New England. It does especially well on sandy land and will grow on sour, but well-drained, soils on which clover and alfalfa do not thrive. For this reason it has come into use in the eastern United States as a winter green-manure crop, or mixed with rye as a hay crop for sandy or sour soils, Fig. 52. Hairy vetch has proved an especially good winter crop in the South because it does not start growth as other legumes do, during temporary warm spells and is therefore not so likely to be killed by severe freezing later.

Roots.—The vetches are all rather shallow-rooted plants, but form a considerable mass of roots in the surface soil and, while the proportion of roots to the total weight of plant is not large, vetch compares well in this respect with most annual legumes and the percentage of nitrogen in the roots has been found to be higher than that in the roots of most annual legumes.

Seeding Hairy Vetch.—In the northern states and on the North Atlantic seaboard, hairy vetch may be seeded later than any other legume, but the best time is from early August to October 15, according to latitude. The plants make little fall growth, but when there is no heaving, will withstand rather low temperatures. In the extreme North, it is best to seed with rye, which will afford protection to the young vetch. About 30 pounds of seed per acre are commonly used in America, but much heavier seedings are the rule in Germany; when seeded with rye, about half a bushel of rye is used. Hairy vetch is one of the best green-manure crops for light, sour soils in the eastern part of the United States, and has been widely recommended for this purpose as well as for an orchard cover and green-manure crop.

FIG. 52.—Hairy vetch and rye, a splendid green-manure crop for the North, the South hairy vetch alone is preferred.
(U. S. Department of Agriculture.)

Purple Vetch *(V. atropurpurea).*—This plant of rather recent introduction, also called black-purple vetch, has been found especially satisfactory in southern California citrus orchards, where it produces an earlier growth and a heavier yield of green matter than any other legume tried. It differs from hairy vetch in its reddish-purple rather than bluish-purplo flowers and by the prominent white scar on the seed. Purple vetch is less winter hardy than common vetch and can, therefore, be used only where the winters are mild. It does best on heavy loams or clay loams provided they are well drained, but has done fairly well on sandy and gravel soils. Its use as a green-manure crop would appear to be limited by its inability to withstand cold, but within this limit it is highly successful, its superiority lying in its ability to make growth in a cool winter season and thus to be ready to turn under at an early date in spring. This feature is important in the southern California citrus groves, where plowing is done in late February or not later than the first of March.

Hungarian Vetch *(V. pannonica).*—Hungarian vetch has creamy or creamy white flowers with a few brown stripes, and hairy foliage. The flowers are borne in clusters of four or less and the pods are hairy. Hungarian vetch is somewhat more winter hardy than common vetch, but less so than hairy vetch and is a safe winter crop only in regions where the temperature does not fall below 10° F. It will succeed on wet, poorly drained soils much better than other vetches and is especially good for such soils as the "white land" soils of Oregon on which common vetch does not survive. Hungarian vetch will not endure hot weather and should not be used as a spring seeded crop.

Woolly Podded Vetch *(V. dasycarpa).*—This is closely related to hairy vetch, but is less winter hardy and is distinguished by its finer stems, nearly smooth leaves and reddish-purple instead of bluish purple flowers, which are very fragrant. The common name is an unfortunate one since the pods are not as hairy as those of the Hungarian vetch and for this reason some confusion has arisen in regard to the identity of woolly podded and

Hungarian vetches. Woolly podded vetch matures earlier than hairy vetch and seeds abundantly so that it should prove a valuable winter legume in sections where hairy vetch matures too late and where the winters are not too severe. The crop is too little known to permit its exact range to be defined, but there is reason to believe that it is fully equal to hairy vetch as far north as Tennessee.

Horse Bean (*Vicia faba).*—This is one of the oldest green-manure crops known in Europe, having been used for this purpose by the ancient Greeks. There are a number of varieties which vary especially in the size of the seed. Those with very large seeds are known as horse beans, broad beans or Windsor beans, and are grown for human food or for stock feed and are not often used for green manuring. Those with small seeds have been successfully used in California and under the name tick bean have been recommended for green manuring under irrigated conditions in New South Wales.

The horse bean is an annual plant with stout, erect stems up to 2 to 6 feet high and pinnate leaves having usually six large oval leaflets. The flowers are fairly large, white, with dark purple markings and are borne on short pedicles in clusters of 1 to 5 in the axils of the leaves. The horse bean is adapted to sections with cool climates, but where the winter temperature does not fall much below 15° F. As a green-manure crop in the United States its use is confined to California. In Germany, France and Italy it is sometimes used as a green manure on the heavier lands.

Other Vetches.—Several other vetches have been tested and some appear to be of possible value. Among them are black bitter vetch *(V. ervilia),* which is more upright in habit than other vetches; scarlet vetch *(V. fulgens),* a rather drought-resistant species; Narbonne vetch *(V. narbonensis),* a rather erect species, but without apparent advantage as a green-manure crop; and narrow-leaved or Augusta vetch *(V. angustifolia)*, a plant of considerable value as a forage crop in the South, but not used for green manuring. Monantha vetch (*V. monanthos)* has of late shown considerable promise in Alabama and in Georgia as a winter green-manure crop.

BUR CLOVERS (*Medicago spp.*)

There are several species of bur clovers, but the one most commonly used in the Southern States is the spotted bur clover *(Medicago arabica),* though the toothed bur clover *(M. hispida),* which is common in California is also used to some extent as a green-manure crop in the Gulf States and in California. Some other species have also been introduced, but have not yet come into general use. The most promising of these newer species is the Tifton bur clover *(M. rigidula),* which is practically immune to the leaf spot sometimes so serious on the common forms. In South Carolina an early variety and a late maturing variety of spotted bur clover have been recognized.

Bur clovers are all prostrate annual plants with small yellow flowers in clusters of 5 to 10 and coiled pods which are commonly beset with spines and form the so-called bur. Bur clovers grow best in cool, moist weather and are consequently winter annuals in a mild climate; they are not winter hardy north of the cotton belt. Within this area, however, bur clover is one of the best winter cover and green-manure crops, as it will grow on land too poor in lime to support red or crimson clover.

Seeding Bur Clover.—The seed of the toothed bur clover is mostly produced in California and is offered in trade as hulled or clean seed, while that of the spotted bur clover is produced in the Gulf States and is sold in the bur. When hulled seed is used it may be seeded broadcast at the rate of 15 pounds per acre and lightly harrowed in or may be drilled at about two-thirds this rate. Unhulled seed must, of course, be broadcast and from 3 to 6 bushels of hulls are required per acre. Seeding should be done in late summer or early fall, the best time in the cotton belt being September. When seeded in cotton, this should be done just after a picking so as to avoid injury to the cotton.

Bur clover has been so widely grown in the South that inoculation is seldom necessary, but when seeded for the first time it is safer to inoculate the seed or the soil. When burs are used for seeding, inoculation is usually not necessary, as some of the nodule organisms are quite certain to be attached to the burs.

FIELD PEAS (*Pisum arvense*)

The field pea or Canada field pea is an annual plant with weak, hollow stems, pinnate leaves, each with one to three pairs of leaflets, and pale, glaucous foliage. The leaves are terminated by one or more pairs of tendrils by which the weak stems cling to supports. The flowers are large, purplish pink or white, and are borne one to three on peduncles which arise from the leaf axils and the green, rarely yellow pods contain several round, smooth or dimpled, brown to black or marbled or speckled seeds. The field pea or Canada field pea must not be confused with the cowpea, sometimes also called field pea in the South. The cowpea is really not a pea at all and it is unfortunate that this name was ever applied to a hot-weather plant. All the true field peas are cool-weather plants and withstand high temperatures as little as low, being adapted to early spring conditions in the North and to culture as winter crop in portions of the South. Some varieties as the Gray winter and the Austrian winter pea, Fig. 53, will commonly endure the winters as far north as Washington, D. C, but most of the varieties can be used as winter crops in the southern portion of the cotton belt only and in most of California.

Roots.—While the root system is fairly extensive, the proportion of the entire weight of the plant that is in the roots is small, being, according to European investigators, less than 5 per cent, but the nitrogen content of the root is said to be fairly satisfactory. Peas are surface rooters and on sandy soils quickly suffer from drought. Sandy loam or loam soils well supplied with lime are best, but a good growth of vines may be obtained on heavy soils.

Seeding Field Peas.—The size of field pea seed differs with the variety, being relatively small in some and large in others, but in all field peas the size of the seed makes it necessary to use a large quantity in order to secure a stand. In the eastern states and under irrigation small seeded varieties are seeded at the rate of 1½ to 2 bushels per acre, while of the large seeded varieties as much as 3 to 3½ bushels are required. The large amount of seed necessary is one of the limiting factors in the use of field peas as green manure, as it makes seeding expensive. The time of seeding varies with the use of the crop; when used as a spring crop, seeding should be done as early in spring as possible in order that full growth may be made before hot weather. In the citrus orchards of California and in the South, peas are seeded in late fall or early winter.

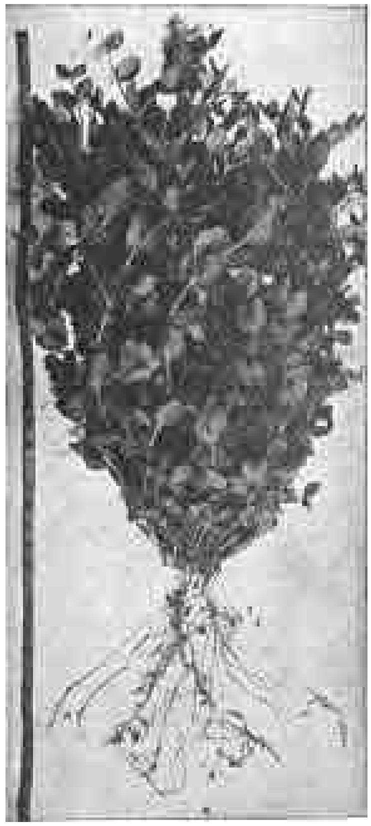

FIG. 53.—Austrian winter pea, showing nodules. Plants dug at Albany, Ga., April 2, 1926. (Courtesy of Mr. W. J. Davis, Tifton, Ga.)

Plowing under Field Peas.—Field peas continue to grow long after the first blossoms have appeared and, when the maximum quantity of organic material is wanted, plowing should be delayed until the first pods are well filled. The requirements of the main crop will, however, be the most important consideration and when peas are to be turned under for cotton, plowing should be done at least two weeks before cotton-planting time. Field peas or mixtures of peas and oats at the rate of 1 bushel of peas and 1½ of oats are well suited as green manure for late potatoes in the North and peas alone are in common use as green-manure crops in southern California. The amount of green material produced is not, however, as large as that secured from some other legumes, being in California only 9 tons per acre as an average of five years, while *Melilotus indica* produced 12¾ tons, and purple vetch 18¼ tons for the same period.

OTHER LEGUMES

Beggar Weed *(Desmodium purpureum).*—Several wild species of beggar weed are natives of the eastern United States, but none is suitable for green manuring, since all are perennial plants making rather slow growth the first season. The plant commonly known as beggar weed in the South is an introduced annual, which has become naturalized in Florida and along the Gulf Coast. The plant is erect, grows 3 to 7 feet high, according to the soil and conditions and has large three-parted leaves. The rosy purple flowers are borne in large panicles at the end of the main stalk and at the ends of the branches. The seed pod is covered with minute hooked hairs, which cause the pods to stick together and make unhulled seed difficult to handle.

Beggar weed is best adapted to sandy lands. When spring seeded, on clay soils at Arlington, Va., it was not able to compete with summer weeds and made a growth of only a few inches. Little attention has been paid to beggar weed, but an early variety has been selected in Florida and is offered under the name of Cherokee clover. This variety will mature seed as far north as Iowa, but for green-manure purposes this feature is not of importance, as the crop can not be used for turning under and for seed production at the same time.

Where beggar weed has become naturalized it volunteers in corn and cotton after the last working and, under such conditions, is without doubt a valuable soil-improving crop. Being a hot-weather annual, it can not serve as a catch crop in the North and, when the entire season is to be devoted to a green-manure crop, it is probable that better results can be secured on most worn-out soils by using cowpeas or velvet beans. In the extreme South, however, and on sandy lands the turning under of beggar weed has been found to give remarkable results. When hulled and scarified seed is available, about 10 pounds should be sown, but 30 pounds will be needed if rough unhulled seed is used. Where beggar weed has not been grown before, inoculation is necessary.

Fenugreek *(Trigonella foenum-grcecum).*—This is an upright growing legume with a central stem and several branches from near the base. The pods are long and pointed and contain small yellowish-brown seeds. Fenugreek is used as a winter green manure in southern California in sections near the Coast, especially in the walnut groves of Orange and Ventura Counties.

Tangier Peas *(Lathyrus tingitanus).*—This is an annual legume resembling somewhat the garden sweet pea to which it is related. It has a well-developed root system, produces a large amount of green material for turning under, and its dense growth enables it to smother weeds. This species is new, but has given promise in the orchards of southern California. The common sweet pea of gardens has also been recommended for use as an orchard green-manure crop in New Mexico, where it is said to have withstood lower winter temperatures than any other pea, in one case as low as 10° F. below zero.

Dalea *(Dalea alopecuroides).*—This plant, which has unfortunately been called Wood's clover, though it has nothing in common with clover except that it is a legume, would better be known simply as Dalea. There are many species in North America, but only a few in the Mississippi and Missouri River regions. Of these the species found by Prof. H. D. Hughes in western Iowa is the only one that has so far given any indication of usefulness. Dalea is an upright annual with pinnate leaves having 15 to 41 leaflets and pink to white flowers on **a** spike 1 to 2 inches long. It has been found growing on heavy and on sandy soil, 2 to 2½ feet high and producing 10 to 14 tons of green matter per acre after wheat harvest, Fig. 70. Dalea is a heavy seeder, producing as high as 10 bushels of clean seed per acre and so far as tested gives promise of being a valuable green-manure crop on many poor soils. It does not do so well on the better lands in Iowa, and has not been tested enough elsewhere to make it possible to judge of its general value. In New York, Dalea is said to have done remarkably well on strongly acid, coarse, sandy soil and to be promising as a green-manure crop for young orchards. On heavier and more fertile soils the crop has not done so well.

LEGUMINOUS GREEN-MANURE CROPS USED IN EUROPE BUT NOT IN AMERICA

Lupines.—The lupine is the most important leguminous green-manuring crop in Europe, being used for that purpose from the North Sea to the Mediterranean. The genus contains many species; some annuals and some perennials, but there are only three species that are important in green manuring, these are the white, the blue, and the yellow lupines, all annuals.

White Lupine (*Lupinus albus*).—This is an erect, somewhat branched, hairy plant with five to seven parted leaves. All lupines are characterized by having palmate leaves, the leaflets of which number from five to nine and are attached to a common point at the end of the leaf stalk, radiating from this point like the fingers on a hand. The large white flowers are borne on long racemes and each flower gives rise to a pod about 2 inches long containing three or four large, pale-yellow seeds.

Yellow Lupine (L. *luteus*).—This has yellow flowers and leaves with seven to nine leaflets.

Blue Lupine (*L. angustifolius*).—This is also known as narrow-leaved lupine and has blue flowers and leaves with seven to nine narrow leaflets, much narrower than those of the yellow lupine. Fig. 54.

In height, the white lupine grows from 1½ to 4 feet, being a larger plant than the yellow or the blue, which commonly reach a height of 1 to 3 feet. The lupines all have a strong root system sending a powerful tap root deep into the subsoil, but the weight of the roots compared with that of the entire plant, while larger than that of some other annuals, is much smaller than is the case in biennials. Where lupines have not been grown before, inoculation is necessary. The seeds of the white lupine are large, while those of the yellow and blue are relatively small in size. For green manuring, the yellow and the blue are preferred, the yellow lupine being used more than the other species. Lupines can not only flourish on sour, sandy soils, but may be injured by too heavy an application of lime unless potash is also added. Gunther and Seidel found that on very sour soil a light application of lime was beneficial, the plants doing best in soil with a pH value of five or six.

FIG. 54.—A field of blue lupines on the slopes of Mt. Vesuvius.
(Photograph by A. J. Pieters.)

Serradella *(Ornithopus sativus)*.—Serradella is an annual or in sections with mild winter climate a winter annual. In Florida the half-grown crop was killed by a temperature of 20° F. The stems are slender, much branched, and semi-erect, with pinnate leaves bearing fifteen to twenty pairs of leaflets. The rose-colored flowers are borne in umbels and the pods are several jointed, these joints constituting the commercial seed.

Roots.—Serradella has a powerful tap root and an extensive root system. According to Werner, the proportion of root, to top is as 1 : 3.3. In spite of this extensive root system, the plant is very sensitive to drought, doing well only on moist sands or sandy loams. A striking characteristic of Serradella is the dependence of this crop on inoculation and on the absence of lime in the soil. It is reported that Serradella frequently fails the first time it is seeded, but that every succeeding time the growth is better because of the increase of the nodule-forming organism. Werner states that the susceptibility of Serradella to injury from lime is decreased with increasing abundance of the inoculating organism.

Owing to its ability to grow on poor sands and its high nitrogen content, Serradella is highly regarded as a green-manure crop in Germany. As far as trials have been conducted in the United States, no definite place has yet been found for it. At Tifton, Georgia, it has given promise except that in a severe winter it is certain to be killed and the growth, when successful, is no better than that of vetches and not so good as that of gray winter peas. In Oregon it has done well in one trial and may be promising. As a spring seeded crop on sandy land in Michigan it has suffered too much from drought to enable it to make much growth. Further trials are necessary before Serradella can be recommended as a green-manure crop in the United States.

Black Medic *(Medicago lupulina).*—This plant is called yellow clover or hop lucerne in Germany and trefoil, yellow trefoil, medic and nonesuch in England, It is not used for green manure in the United States, but in Germany and France has given good results when used as a companion crop to be turned under for a hoed crop in spring or in fall for a following grain crop.

Black medic is a clover-like plant with many prostrate branches arising from a crown. When sown alone in spring the plant is an annual, but when held back by the grain crop or when seeded on stubble, is a winter annual. The flowers are deep yellow and borne in small heads and the pods are black, whence the name black medic. This plant is fully as winter hardy as red clover and starts growth early in spring. It is closely related to the bur clovers, but makes less growth than they do on poor, somewhat acid soils. A larger and later variety has been developed in Denmark.

TROPICAL AND SEMI-TROPICAL GREEN-MANURE LEGUMES

The tropical legumes used or useful as green manures are very numerous, more than 100 having been mentioned by various writers as being used, as under test, or as promising. With the exception of the velvet bean, the cowpea, and the soybean, these are all species not generally used or known in the United States. One of them, *Crotalaria striata,* has been introduced into Florida and is used there to some extent as an orchard green-manure crop, and the pigeon pea *(Cajan indicum)* has been grown experimentally. Only a few of these tropical legumes will be mentioned here. For descriptions of and notes on many others the reader is referred to the following numbers in the list of literature; 50, 118, 147, 196, 299, 349, and 398.

Genge *(Aslralagus sinicus).*—The genge of Japan is the chief green-manure plant of China and Japan. The species is a weak-stemmed, procumbent biennial or winter annual with pinnate leaves on long petioles; the leaflets vary in number from three to five and the rose-colored flowers are borne in umbels. Two varieties are said to occur in Japan, one is used as forage and another, a more vigorously growing form, attaining a height of 4 feet or more, is cultivated especially for green manuring. The seed of genge is sown among the ripening rice in September or October, when irrigation is discontinued, and the plant blooms in early May, at which time it is dug into the ground. Genge can be grown only on lands that can be allowed to become quite dry after rice harvest. A good crop will produce 9 to 10 tons of green matter for turning under and, according to Kellner,[146] this contains 0.369 per cent of nitrogen.

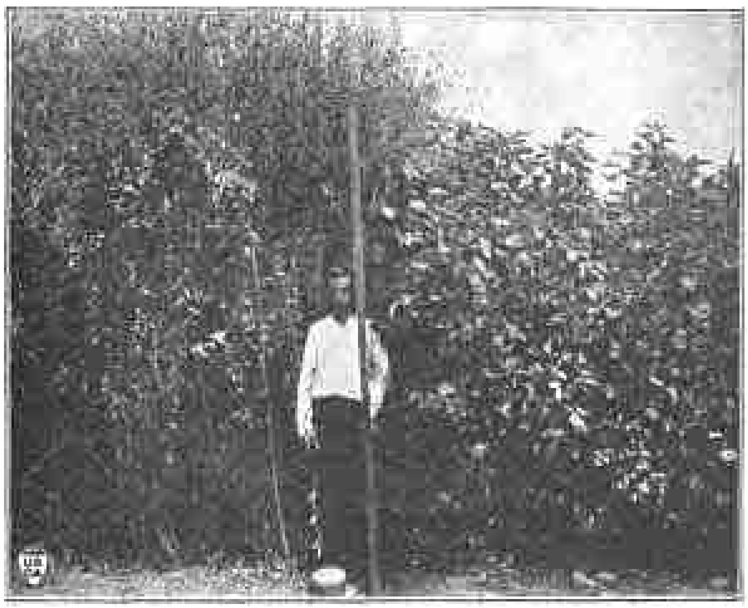

FIG. 55.—The Crotalarias produce a great mass of organic matter. At the left, *C. juncea,* at the right *C. striata,* grown at the Porto Rico Agricultural Experiment Station. (U. S. Department of Agriculture.)

Sunn *(Crotalaria juncea).*—This is one of the most widely used green-manure plants in India, but appears not so often used at high elevations or in the East Indies. Crotalaria juncea, known as Sunn, Sunn-hemp, Sann-hemp, sann, san, sanai or as tag hemp, is a stiff, shrubby annual, growing several feet high and with woody stems and stiff branches, Fig. 55. The leaves are l½ to 3 inches long and shiny on both sides with brown, silky hairs. The bright yellow flowers are borne twelve to twenty in loose racemes about 1 foot long. Sunn is best adapted to the lighter, better-drained lands and does not succeed as well as Sesbania in low, wet lands. It is chiefly used as a green manure for rice, but has also been turned under as a preparation for sugar cane, for tobacco, onions, garlic, and wheat. The turning under of Sunn is done in various ways; it is pulled up and laid in furrows, plowed under while standing or is sometimes beaten down with sticks, trodden down by cattle, or planked down. In some parts of India there are two varieties of Sunn, the Boran, grown for fiber and the chotna, grown for green manuring, but not for fiber.

Other Crotalarias.—Several other species of Crotalaria have been used in various parts of the tropics. *C. striata* and *C. usaramoensis* have been used in tea gardens and *C. anagyroides* is said to be of rapid growth and to furnish large quantities of green material for turning under for rice. It is said to do fairly well at an altitude of 5000 feet in Java, although at this altitude growth is slower.

Crotalaria striata has become of some importance in Florida, where it is rather extensively used as a green-manure crop in citrus and other orchards. Other species have also been tested, the most important of which are *Crotalaria sericea* and *Crotalaria incana.* At present, however, *Crotalaria striata* is undoubtedly the most important and promising for Florida conditions, Fig. 56. The Crotalarias offer promise as summer green-manure crops on very poor sandy land in the South, and deserve further testing.

Sesbania *(Sesbania aculeata).*—This is known as dhaincha, or sawri, and is another common leguminous green-manure crop in India. It is a shrubby annual, growing to several feet in height, the branches and leaf

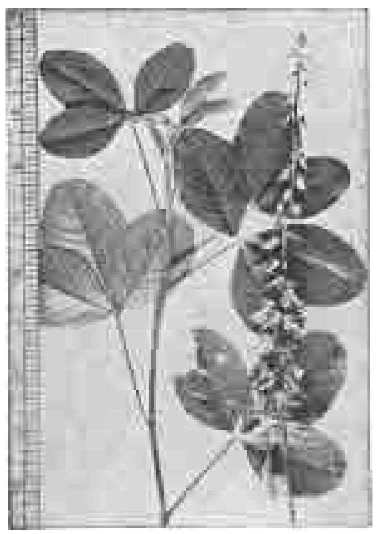

FIG. 56.—Leaves and flowers of *Crotalaria striata.*
(Florida Agricultural Experiment Station.)

stalks armed with small, weak prickles. The pinnate leaves bear forty-one to eighty-one narrow leaflets and the pale yellow, red-dotted flowers are borne three to six in a loose raceme. The pods are long and very narrow. Sesbania is better adapted to wet lands than Crotalaria and thrives at higher altitudes, will endure considerable drought and salinity in the soil and will grow on very poor land. It is not useful for forage and is consequently grown as a green manure only. *Sesbania aculeata* is said to have a strong, deep root system and this fact has been mentioned as an advantage when it is desirable to open up a subsoil. Species of Sesbania also occur in the United States and one of them at least, *S. macrocarpa,* Fig. 75, which grows wild in California and Arizona on the overflow lands of the Colorado River, is sometimes used there as a green manure. This is a rapidly growing hot-weather annual, the seed not germinating until June, but the plants grow so rapidly as sometimes to attain to a height of 6 to 8 feet in as many weeks. The pods are 8 to 10 inches long and root system shallow so that the plant does not thrive where the soil dries out. Another species, *S. aegyptica,* is a soft-wooded perennial shrub of short duration and is used for green manuring in Formosa.

Pigeon Pea, Porto Rican Pea, Arhar in India *(Cajan indicum).*— This is a shrubby perennial in the tropics where it is found nearly everywhere. It attains a height of 3 to 10 feet in Hawaii, with slender, very leafy stems and, when not crowded, well branched at the base. The growth at first is rather slow and spindling but it matures a crop of seed in seven to eight months and, when cut back, the new growth is said to be especially leafy. The leaves are three-parted and the yellow, or red and yellow, flowers are borne in racemes. Krauss [162] mentions several varieties as being grown in the Hawaiian Islands. The use of the pigeon pea as a green manure appears to be very limited; it has been tried in tea gardens in India, but has not proven satisfactory there.

Boga-medeloa (*Tephrosia Candida)* is a perennial shrub native to the lower Himalayan hills. The woody, grooved branches are clothed with thin brown bark and bear pinnate leaves, each with nineteen to twenty-five leaflets. The white, cream-colored or reddish flowers are borne on lateral or terminal racemes 6 to 9 inches long. This plant has a strong root system and is said to grow on all kinds of soils at from sea level to an altitude of 6000 feet. It is, therefore, useful in many situations both in India and in the East Indies and has been used in such widely diverse cultures as Hevea, tea, coffee, cacao and cinchona. The plants are cut two to twelve times per year, in some cases only the side branches being lopped, while in others the entire plant is cut down at a height of 1 to 2 feet; the prunings are dug into the soil. New growth is promptly produced but when 3 to 3½ years old or earlier the bushes are dug out and buried and new plantings are made. Various other species of *Tephrosia* have been tried and of these *T. purpurea,* a perennial herbaceous plant, has given most promise.

Dadap *(Erythrina lithosperma).*—Much of the green manuring in the tropics is done by lopping branches of trees and shrubs and burying these prunings where wanted. This is especially true in tea gardens and one of the trees used in this way is the thornless dadap, *E. lithosperma.* This, if allowed to grow freely, becomes a tall tree with large three-parted leaves, each leaflet being 4 to 6 inches in length. The large, coral red flowers are borne in dense racemes. Dadap is a native of Java and the Philippines, but has been used in the tea gardens of India. Wright [349] advises propagation by cuttings, each 5 feet long and 2 inches in diameter set the same day they are cut and in the rainy month of June. The young trees are lopped every two months or less frequently and are said to produce large amounts of green matter for digging into the ground. It does not appear that the use of this tree is very general and some fear is expressed that it may become a source of disease infection for the tea. Some writers claim that, except on heavy soils, every advantage offered by dadap can be more cheaply and safely secured by the use of *Tephrosia Candida.*

The Sau *(Albizzia stipulata)* tree is a native of the tropical Himalayas up to 4000 feet altitude. The leaves are bi-pinnate and have twelve to forty pinnae each with many small leaflets ½ inch or less broad. The Sau tree appears to be used only in tea gardens and is said by Mann and Hutchinson to be the first green manure to be used for tea gardens and remains to this day, on the whole the best. The Sau tree appears to be valued more for its shade effect and for the effect of the roots on opening up the subsoil than as a green manure plant. Another species, *Albizzia moluccana,* is cultivated in tea gardens in Ceylon.

Besides the species described, many other leguminous plants are more or less commonly used and a very large number have been tested and described by Van Helten [299] and Keuchenius. Among the more important of these are species of *Phaseolus, Dolichos, Vigna,* especially *V. hosei, Mimosa invisa,* which, however, appears to be valued more as a ground cover and weed destroyer than as a true green manure, *Cen-trosoma pubescent* and *C. plumieri,* species of *Desmodium,* especially *D. gyroides,* species of *Indigofera, Calopogonium mucunoides,* used as a ground cover between young sisal plants, and many others.

NON-LEGUMINOUS GREEN-MANURE CROPS

Crucifers.—Of the cruciferae, white mustard *(Brassica alba),* rape *(B. napus),* and cow-horn turnips *(B. rapa)* have been used for green manure both in America and in Europe. White mustard is a tall annual with pinnatifid, rough hairy leaves and large pale brown seeds. Rape is a biennial cultivated forage crop with large smooth leaves. It is a rapid grower in cool moist weather and produces a large amount of green material for turning under. The cow-horn turnip is a variety distinguished by its enormous elongated root, which constitutes the bulk of the organic material for turning under. These roots are 2 feet or more long and 2½ to 3 inches in diameter with 3 or 4 inches of the root above ground. As cow-horn turnips are commonly seeded in late summer and are not winter hardy, the roots are dead and decaying when turned under.

Grains and Grasses.—The grains are too well known to require description. Most of them have been used as green manure or as cover crops, but rye is doubtless the one most commonly so used. Its ability to make some growth even when planted late and its extreme winter hardiness commend it in the North for situations requiring late planting. In the South, the Abruzzi rye has been found to be best. Wheat, oats, barley, corn and the sorghums have been used as green manures, but for most of these such use is rare and sporadic. Millet is useful as a cover crop, but is not used as a green manure.

Buckwheat *(Fagopyrum esculentum).*—Next to rye this is probably the most common non-leguminous green-manure crop and is especially used on poor lands in the North. It is a quick-growing annual with broad, triangular-heart-shaped leaves and white flowers borne in corymbose racemes at the top of the plant. Buckwheat can use relatively insoluble fertilizers, like rock phosphate, better than corn or small grains and can, therefore, grow on poorer land. It is a favorite bee plant. A mixture of buckwheat and peas is said to make a good orchard cover crop in New York, where the heavy growth is rolled flat at apple-picking time and makes a desirable ground cover. In Michigan, peach orchards on sandy land are reported to have been injured by the use of buckwheat as a cover crop.

Weeds.—Various weeds serve to maintain the organic matter of the soil and in so far as they do so may be considered useful. In some sections where the summers are dry, such weeds as ragweed cover the fields after grain harvest under conditions which clover or other cultivated plants could not endure. Similarly, the corn fields on good land are often overgrown with late summer weeds which, after corn is laid by, may attain a height of 2 or more feet and add several hundreds of pounds of organic matter per acre to the soil. Analysis of some weeds has shown that they may contain large quantities of plant nutrients which are, of course, returned to the soil from which they came. The weeds that are somewhat useful in this respect vary in kind in different sections of the country. On the sandy lands of eastern Maryland, Delaware, and in parts of Virginia the partridge pea, *Cassia chamaecrista,* which in the eighteenth century was used as a green-manure plant, still flourishes here and there and adds nitrogen to the soil. The Mexican clover *(Richardsonia scabra),* a plant which is so far from being a clover at all that it is not even a legume but a member of the coffee family, grows spontaneously and abundantly on the sandy soils of the extreme South and helps to maintain the humus content of cultivated soils. On rich soils as on the heavily fertilized tobacco fields of Connecticut, chick-weed *(Stellaria media),* flourishes in late summer and fall and produces an appreciable quantity of organic matter.

While weeds are not to be recommended as green-manure plants, they come without expense and, when they cover the ground at a time when there are no crops, it is probable that they do more good than harm. They certainly absorb nitrates that would otherwise go to waste, but can be conserved by being transformed into organic nitrogen and can be made available to crops at a later date. They also, in many cases, add the humus so indispensable to good soil tilth.

SUMMARY

The most important green-manuring crops are legumes and, in respect of climatic adaptations as well as agricultural use, those used in America may be arranged roughly in four classes: (1) those which grow as companion crops during the summer, remain dormant in winter and begin rapid growth in spring—red, alsike and sweet clover; (2) those which are seeded in the fall and remain dormant or in favorable sections make a little growth during winter and a rapid growth in spring—crimson and bur clover, the vetches, yellow annual melilot; (3) those which grow in summer only—cowpeas, soybeans, velvet beans, beggar weed; (4) those which thrive in cool weather only, either where the winters are mild or in early spring elsewhere—the field pea is the only representative of this class.

While red and alsike clover and alfalfa are not often used as purely green-manure crops, they are sometimes so used and are of great importance as rotation crops to maintain the organic matter and nitrogen content of the soil. Sweet clover is already an important green-manure crop and promises to become the most important crop for this purpose in America. The cowpea and the velvet bean are the leading summer green-manure crops, while, considering all parts of the United States, vetches are probably of greater importance as winter green-manure crops than any others. In Europe the lupine is by far the most important purely green-manure crop, while clover fills an important place as a maintainer of soil productivity on the better lands.

In the tropics, the line of division between crops used for cover or shade and for green manuring is not sharply marked. Many legumes are used more or less for two or more purposes, but whatever other place such a crop may fill it is also expected to provide organic matter for soil improvement. While cowpeas, soybeans and velvet beans are used in the tropics, the chief crops used are entirely different from those used in America or in Europe, some of the most important ones being of a shrubby nature.

Non-legumes are used to a less extent than legumes, but rye has a very wide range of usefulness and is especially adapted to situations requiring very late seeding or very early plowing. Besides the grain crops and buckwheat, the crucifer family furnishes practically all other non-leguminous plants used for green manuring. Weeds are useful as far as they go and may often add considerable stores of organic matter to the soil.

CHAPTER XII

GREEN MANURING IN THE UNITED STATES

GREEN manuring is not yet a general practice in the United States, though there are sections in which green manuring is as much a part of the local agricultural system as the use of fertilizers and there is no doubt that the use of green-manure crops has received a great impetus in the last twenty years. The extent to which green manures are used is somewhat obscured by the use of the term "cover crop," which is in rather common use in many parts of the country. This term is used to include crops that are purely cover crops as well as those that serve first as cover and later as green-manure crops. However, with the exception of those sections in the extreme North or in the Great Plains where orchard cover crops are grown solely for their protective effect, cover crops are frequently used as green-manure crops also.

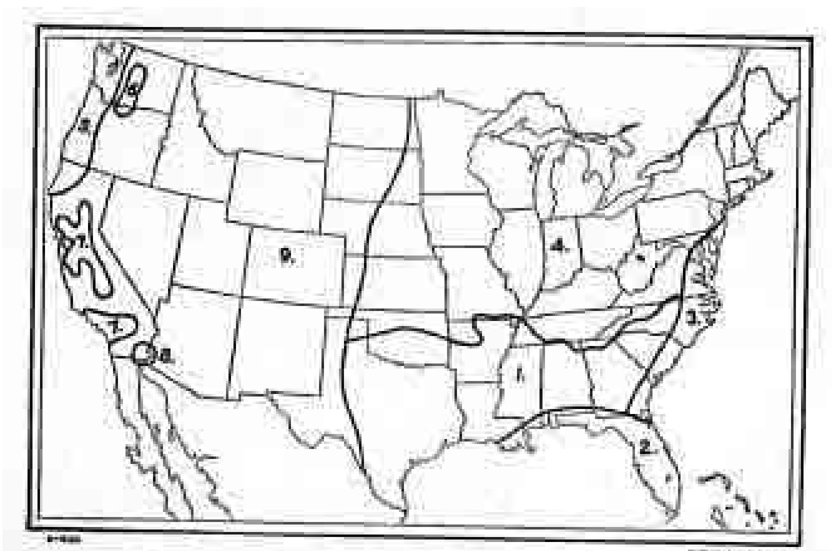

FIG. 57.—Outline map of the United States showing chief green-manure areas. The principal crops used are:

Area 1, Cotton Belt	Winter cover crops	Bur clovers. Vetches, Austrian winter pea, *Melilotus indica*
	Main crops and Catch crops	Cowpeas Velvet beans Beggarweed
Area 2, Gulf Coast and Florida	Winter cover crops	Bur clovers Vetches Austrian winter pea
	Main crops, Catch crops or Summer orchard green-manure crops	Cowpeas Velvet beans Beggarweed Crotalaria

Area 3, Atlantic Coast section	Winter cover crops	Crimson clover Vetch and rye Rye
	Main crops or Catch crops	Cowpeas Velvet beans Soybeans Cowhorn turnips Cowpeas and sorghum
	Companion crop	Sweet clover
Area 4, Clover Belt	Winter cover crop	Hairy vetch and rye Rye
	Main crops or Catch crops	Red clover, second growth or mammoth clover Soybeans Cowpeas Hubam
	Companion crops	Sweet clover Red clover
Area 5, Northwest Coast.		Vetches or vetch and grain.
Area 6, Northwest. Apple section.		Alfalfa Red clover Vetch
Area 7, California Orchard section	Winter crops	Vetches *Melilotus indica* Canada field peas Horse beans
	Summer crops	Cowpeas Soybeans
Area 8, Imperial and other valleys	Winter crop	*Melilotus indica* Vetches
	Summer crops	Sesbania Cowpeas

Area 9, Practically no green manuring except in certain areas under irrigation.

It will be most convenient to consider the use of green manures in North America by regions and under the main crops for which green manures are used in each region. The geographical outlines of these regions are shown in Fig. 57 and are roughly the Cotton Belt, the Gulf Coast and Florida, the North Atlantic Seaboard, the Northeastern United States and Canada, including the Corn Belt, the Great Plains and the Pacific Coast and Southwest.

Under each region the green-manure practices followed in growing the main crops will be described as far as information is available.[1]

[1] The author wishes to make special acknowledgment of material help received from many county agents and other correspondents who have furnished information relative to the practices in their localities.

The agricultural experiment stations in the South have been actively interested in the problem of soil improvement and have shown that green manuring will increase yields. However, it remains doubtful whether the turning under of a summer legume crop is economically justifiable except on the poorest soils. The more common practice is to cut the summer legume for hay or to allow stock to graze it and to depend upon the residues for soil improvement. When a crop of velvet beans is grazed off a large amount of organic matter is returned to the soil and to a certain extent the same purpose is served as though the entire crop had been turned under. A winter legume, however, does not interfere with the regular summer crops and may profitably be turned under for corn or cotton.

This practice is definitely increasing in the South and there are cases where very material soil improvement has been accomplished and yields have been increased on both poor and good soils, sometimes by straight green manuring and in other cases by a modified system which, while yielding cash returns, has also enriched the soil with organic matter.

While several of the agricultural experiment stations in the South have been active in urging the use of green manures, the practice is sometimes attended with difficulties not easily overcome. Summer legumes, as cowpeas and velvet beans, are easily grown, but these occupy the ground for one entire crop season unless they are seeded as catch crops in corn and even in that case the legume is likely to be more profitable for feeding than for turning under. The ideal green-manuring crop for the South is a winter legume, but in some sections crops and methods that will insure a stand of a winter legume have not been fully worked out. This is especially true of sections like part of Georgia, where the late summer and fall months are commonly dry, or where, in parts of the coastal plain in Georgia, the soil is poor and many winter legumes make an unsatisfactory growth. Another difficulty encountered in many parts of the South is the fact that warm spells in winter may stimulate growth only to be followed by severe cold by which the crop is killed. In many respects, therefore, the problem of finding the right winter legume green-manure crop is a difficult one in the Southern States, but it seems probable that, with more experience, it may become possible to secure good results more regularly.

Green Manuring for Corn.—The winter legumes most used in the South for the green manuring of corn are hairy vetch, crimson clover and bur clover. In the absence of statistics, it is impossible to make any statement regarding the relative importance of each of these three. In some sections, as in Alabama, hairy vetch is certainly more important than the others, and in Virginia, crimson clover is most generally used. With the exception of Virginia and Tennessee, where bur clover is not hardy, all of these legumes are used to some extent throughout the cotton belt as far west as the Mississippi River. Except in the sugar-cane plantations of southern Louisiana, green manuring is not practiced in that portion of the cotton belt lying west of the river. The use of vetch has increased during the past few years and, while woolly podded, Hungarian, Monantha, and common vetches have been tried, hairy vetch is by far the most popular species. The increase in the use of this seed is shown by the following figures furnished by J. T. Williamson of the Alabama Polytechnic Institute: "In 1920, about 10,000 pounds of vetch seed were bought cooperatively; in 1921, 35,000; 1923, 315,000; 1924, 515,000, and in 1925, approximately 600,000." Besides the seed bought cooperatively, considerable quantities were handled by the trade. It is estimated that 1,500,000 pounds of hairy vetch were seeded in Georgia in 1925 and that a large part of the acreage seeded was used for green manuring. The practice in Alabama is typical of that followed in other parts of the South. Vetch is seeded in September and October, at about 20 pounds per acre, being broadcast and covered, or it is drilled with a three-row grain drill which has a specially prepared vetch plate.

The vetch may be turned under in March, so that the land will be ready for cotton by April 10 or the vetch may be allowed to stand a few weeks longer and be turned under for corn. It is said to be practicable to seed vetch after cotton and turn it under for another crop of cotton if desired. The Alabama extension authorities, however, advise a rotation of cotton with vetch seeded in the cotton and turned under for corn. A summer legume seeded in corn is turned under for cotton the following year. In this rotation the vetch uses the phosphate left by the cotton and longer time can be allowed for the growth of the vetch than if it were turned under for cotton. It was estimated that in the winter of 1926 more than 5000 acres were in vetch in Dallas county, Alabama, and that half of this would be turned under for cotton.

Increased yields of cotton of 100 per cent and more are said to follow the use of vetch. In some cases the vetch is allowed to seed and it then becomes a volunteer crop. The Mississippi Agricultural Experiment Station reports: "We have land on the station that is capable of growing two bales of cotton per acre, that would not produce one-half bale per acre nineteen years ago. All of this improvement has been brought about from growing vetch from only one seeding. The plats are allowed to mature some seed every other year."[1] .

In parts of North Carolina, good results have been secured by scattering the vetch seed among corn, soybeans, or cotton in September. If the soil is inoculated, good results follow but it must not be forgotten that wherever vetch is used for the first time the soil or seed must be inoculated. In North Carolina the vetch can not be turned under in April, as sufficient growth has not been made and plowing is delayed until about the middle of May. Late planted corn after vetch has made excellent growth on poor land without the addition of any other nitrogenous fertilizer. In South Carolina, the use of hairy vetch has in some cases improved poor lands to such an extent that the yields of corn have increased from less than 10 bushels to more than 50 bushels per acre, and it is said that frequently the yields of corn are doubled after turning under one crop of vetch.

Crimson clover is not much used in the Gulf states, but is an important crop in the Carolinas and in Virginia, is successful in Northeastern Georgia and is sometimes used in Mississippi. The use of crimson clover and its value for corn under Virginia conditions have been described (p. 164) and it is enough to say here that, on all the light but not extremely poor sands of North and South Carolina, it is capable of causing material improvement in soil productivity.

Bur clover has long been known and used in the Gulf States, but its extension into South Carolina is of a more recent date. The outstanding characteristic of bur clover is the fact that, where it can be allowed to mature seed, there will nearly always be a volunteer crop the next year. Once land is well seeded, therefore, there is no further need of preparing

[1] 38th Annual Report of the Mississippi Agricultural Experiment Station, p. 37, 1924-1925.

land and seeding, an advantage that naturally makes a strong appeal. Many farmers will use a crop of this sort when they would not buy vetch or clover seed and attend to seeding at the proper time to get the best results. When land is once well seeded to bur clover, the clover volunteers after the last working of corn or cotton and a stand is assured unless the land is worked after the young clover comes up. Bur clover does not ripen early enough to produce seed at the time plowing must be done, but a volunteer crop can be secured by leaving unplowed strips between some of the corn rows. The clover on these strips may be allowed to ripen and the burs will be scattered by the subsequent cultivation.

In South Carolina, where the extensive use of bur clover is of more recent origin, a method of seeding has been developed which insures a stand when bur clover is seeded for the first time on poor land. By this method the burs are first layered with manure in a wagon box and the mass is then thoroughly worked over and mixed. A fork full of the mixture is placed on the ground at intervals of 2 to 5 feet and from these centers the clover soon spreads over the entire field. Corn yields in South Carolina are said to have been doubled after turning under one crop of bur clover.

FIG. 58.—Corn and velvet beans after green manuring on Cherokee Farms, Monticello, Fla. (Courtesy Mr. Chas. F. Leach.)

In northern Florida, a badly run-down field has been brought up to a high state of productivity by a combination of green manuring and the wise use of crop residues. In 1919, this field was planted to corn, but did not produce a single ear. Sorghum and cowpeas were seeded later in the season with 200 pounds of mixed fertilizer, but even the cowpeas made little growth. This crop was grazed for a week and what was left was turned under and oats seeded. These, too, made little growth and were grazed by hogs. In May, 1920, the field was plowed and seeded to beggarweed, which grew 3 to 4 feet high, was allowed to seed, and was all turned under. This was the first distinctly green-manure crop and oats which followed did well. In 1921 sorghum and cowpeas were planted on the upland and hillsides and Spanish peanuts in the bottom. The sorghum and cowpeas were cut for hay after which beggarweed volunteered. The beggarweed and peanuts were hogged down, and the land fitted for rye, which made a splendid crop. A heavy crop of beggarweed in the summer of 1922 was followed by oats for pasture the next winter, with beggarweed and peanuts in the summer of 1923. These were hogged off, but naturally much organic matter remained to be turned under for oats for winter pasture. In April, 1924, all the upland and hillside was planted to corn, with Spanish peanuts in the middle, and velvet beans every 2 feet in the corn rows. The corn yielded 49½ bushels per acre, and the velvet beans made 15 to 20 bushels. After harvesting the corn and velvet beans, the cows and hogs were turned in to harvest the peanuts and later the corn stalks and all the velvet bean and peanut residues were turned under. Oats and rye for winter pasture was followed by corn in April, 1925, with velvet beans every 2 feet in the corn rows. The yield per acre was 81 bushels of corn and 1400 pounds of velvet beans in the pod, Fig. 58. This experience, for an account of which the writer is indebted to Mr. Charles F. Leach, shows how it is possible to bring up run-down land by a judicious use of green manures and crop residues both of which add organic matter to the soil. In 1919 this land was worthless, in 1925 it was highly productive.

Green Manuring for Cotton.—Cotton is the most important crop in the South and must be planted early, so that winter green-manure crops will not have attained their maximum growth or will not have matured at plowing time. As pointed out, cotton is very liable to injury if the germinating seeds or the young seedlings are subjected to some of the composition products of decaying organic matter, though the precise nature of these harmful substances is not at present known. While, therefore, corn can be planted after crimson clover is ripe and the seed has been harvested, this can not be done with cotton, for which the clover must be turned under when in full bloom or a little earlier. When a large acreage of cotton is to be planted after crimson clover has been turned under, some of the clover must be turned early in order that the entire acreage may be handled in time. One of the pioneers in the use of crimson clover as a green manure for cotton is Mr. B. S. Hodges, of Hodges, South Carolina, whose system has been described by Sherard. This is one of the outstanding examples of the value of green manuring on the sandy lands of the South. Hodges uses the "balk system," but only when the acreage of clover to be turned under for cotton is larger than can be handled in the regular way. In this system, strips 4 to 4½ feet apart are plowed in the clover and prepared for cotton planting, leaving the balks, or strips of clover some 18 inches wide for later attention. On these balks the clover may be left to mature and seed may be gathered or it may be worked down when convenient before the seed has matured. A somewhat similar system is in use in northeast Georgia, Fig. 59, but in this section the ripe crimson clover is so deeply covered that the seed is said to remain without germinating until uncovered by later working in the fall and a volunteer stand consequently results. The Georgia system is said not to be practicable on the sandy soils of South Carolina.

The work done by Hodges in South Carolina has demonstrated the value of crimson clover as a green-manure crop for cotton and it has been claimed by Hodges that after turning under crimson clover on poor land for three years the yield of cotton was increased 500 per cent. He states that on good land the use of a green-manure crop may not greatly increase yields, but will save the fertilizer bill and prevent soil deterioration.

FIG. 59.—Growing cotton after crimson clover by the balk system, Northeastern Georgia. Note the young cotton plants in the plowed strips between balks.
(Photograph by L. W. Kephart.)

When using crimson clover for the first time on poor sandy land, inoculation is necessary or at least advisable, and a light dressing of manure or lime will help to secure a stand. Repeated seedings without inoculation, manure or lime may accomplish the same result and it is quite possible to eventually secure a good stand and growth of crimson clover without any special effort, but several years may be spent in the attempt, while proper attention to inoculation, manuring and liming will accomplish in one year what it may otherwise take several years to do. The above statement does not, of course, apply to the better soils.

The use of crimson clover as a winter green-manure crop would doubtless be more extensive than it is were it not for the fact that it is often hard to secure a stand. This condition appears to be associated largely with a lack of moisture in late summer and fall and it may be repeated here that, where rainfall is uncertain, unhulled crimson clover seed has given better results than hulled seed.

Bur clover has also been used as a green manure for cotton and in this case, too, the balk system is used especially when a volunteer crop of bur clover is desired. Furrows are laid off about every 4½ feet and, since the immature bur clover decays quickly, no trouble is experienced in preparing the seed bed for cotton. Later, when the burs have ripened on the strips left at plowing time, these strips are worked down and the burs are scattered by the subsequent cultivation.

Hairy vetch, while mostly turned under for corn, is also sometimes used for cotton and a report from South Carolina states that poor land producing only 300 pounds of seed cotton per acre has been improved by the use of vetch to a point where the yield of seed cotton was 1500 pounds per acre.

Soybeans and cowpeas, grown as catch crops after grain or seeded at the last working of corn, are occasionally turned under as green manure in Virginia, but the use of soybeans as a green manure is rare. A practice becoming more common and a more advantageous one is to harvest the beans and leave the soybean residues on the ground. This adds organic matter, while at the same time, the ground is producing a crop.

While the use of winter legumes such as vetch, crimson and bur clover as green manures for corn and cotton doubtless involves turning under the legume before maximum growth has been attained, it is not improbable that the regular use of such limited amounts of organic matter is more beneficial than the turning under of a larger mass of a summer green manure, as velvet beans. In the latter case, there is almost certainly a considerable waste of nitrogen, while when the winter legumes are turned under, decay and utilization go on together and the growing corn and cotton are in position to take full advantage of the nitrates produced. A rather special case of the use of a green-manure crop with crop residues may be cited to show that even on the rich delta lands of Mississippi the addition of organic matter has been beneficial. Red clover was seeded with oats in October and was turned under in June after the oats were harvested. Soybeans followed and were hogged off, leaving considerable quantities of plant residues to be turned under for cotton the next year. It is claimed that this practice has increased the yield of seed cotton by more than 700 pounds per acre. On the good soils of the delta, red clover lends itself well to use as a winter cover and green-manure crop when the following crop does not need to be planted early.

Green Manuring for Truck Crops.—On the sandy soils about Norfolk and elsewhere in Virginia, trucking has become a highly developed industry and in the past the truckers have used large quantities

FIG. 60.—Plowing under sorghum for green manure at the Virginia Truck Experiment Station, Norfolk, Va. (Virginia Truck Expt. Sta.)

of stable manure. The increasing price of stable manure has, however, compelled many of them to turn to green manures, supplemented with commercial fertilizers, and in Northampton and Accomac Counties, Va., many farmers have modified their cropping systems so as to include a green-manure crop. Valuable experimental work on this subject has been done by the Virginia Truck Experiment Station and the writer is indebted to Prof. T. C. Johnson, director of this station for details in regard to the practices in use. Following a winter crop of kale or spinach, cowpeas or soybeans are seeded and usually turned under for the next crop. Rye is still the most commonly used winter cover crop, though the experimental work at the station has shown that crimson clover can be advantageously used as a catch crop or as a winter cover crop and that, when supplemented by commercial fertilizer and lime, it can replace large quantities of expensive stable manure.

In the potato-growing section about Norfolk early potatoes are often interplanted with corn. After corn harvest and between July 15 and August 15 rye is seeded and turned under in January or February for early potatoes. At the Virginia Truck Experiment Station sorghum, Fig. 60, was substituted for corn and was turned under in September or October, and the ground left rough till spring. The record of one experiment has been kindly furnished by Professor T. C. Johnson and shows that, on the light soils at Norfolk and where the crop is heavily fertilized, non-legumes may be as effective as legumes. The same amount of commercial fertilizer was used on all plats and the yields of potatoes, in bushels per acre were as follows:

	Prime	Culls
Check plats (average of 4)	61.1	8.0
After cowpeas	132.0	10.5
After sorghum	151.0	12.0
After soybeans	142.0	62.0
After grass (weeds)	133.0	9.0

Sorghum sown thickly at the rate of 2 bushels per acre, produces a large mass of organic matter for plowing under and appears to offer promise as a quick growing catch crop. The cropping season was unusually dry and partly accounts for the low yields but it was noted that the potatoes on the green-manured plats did not suffer as much from drought as those on the check plats.

Whether equally good results would follow in case a winter crop is planted after sorghum is not known, but the turning under of so large an amount of energy material low in nitrogen may be expected temporarily to have a depressing effect on the quantity of nitrate available. Several months later, when potatoes are planted this effect has evidently passed.

In the bright tobacco section of Virginia, rye and redtop are often used as green-manure crops for tobacco, but legumes are not used as they are believed to have a bad effect on tobacco. This is especially true of soybeans and cowpeas. In the dark tobacco region, rotations including grass and clover for the last year obviate the need of a special green-manure crop and, in general farming practice, rotations which include clover are commonly depended upon to maintain soil productivity. The introduction into the South of a type of soybean harvester which removes the beans while returning the residues will doubtless have an important effect, as by this means the soil organic matter can be kept up. It should, however, prove possible and profitable to use a winter cover after the soybeans if for no other reason than to prevent the loss of fertility, which must certainly take place if the soil is left bare.

Green Manuring for Sugar Cane.—In the sugar-cane growing section of Louisiana, *Melilotus indica* may be seeded in the fall-planted cane, and this practice, though of relatively recent origin, is being extended with good results. Seeding is done in October and the growth is turned under in spring, about the time of early bloom. The *Melilotus* must be turned under before full growth is attained, as it has been found that if left standing until late spring damage to the cane may result, especially if turning under is followed by a period of dry weather. The neglect of this fact has, during the rather dry year, 1925, resulted in some damage to cane and in much unwarranted condemnation of the green manure. Where the crop is turned under early and dry weather follows, no harmful results have been reported. The increase in cane secured in experiments with *Melilolus indica* as green manure have been referred to on p. 182.

FIG. 61.—The velvet bean is often used as a summer green-manure crop in pecan orchards. (U. S. Department of Agriculture.)

The common method of green manuring cane is associated with a three- or four-year rotation system. In this the stubble cane is followed by corn and soybeans are planted in the corn or may be planted alone. After the corn is harvested and what hay is needed has been secured, the field is rolled and the immense debris of corn stalks and legume is turned under for the following crop of cane. The Biloxi soybean is commonly used and has largely replaced cowpeas, which were formerly used in the same way.

FIG. 62.—The Austrian winter pea is a promising winter green-manure crop in Georgia. (Georgia. Coastal Plains Experiment Station.)

Green Manuring in Pecan Orchards.—When special crops are grown, as sugar cane in Louisiana, green manuring is more often resorted to than in general farming and this is the case in pecan culture in Georgia and northern Florida. The soils on which pecans are planted are commonly deficient in organic matter and the importance of adding this has been realized by the better planters. The velvet bean as a summer green-manure crop is more commonly used than any other, Fig. 61, though the use of beggarweed is not uncommon and in young orchards cowpeas are sometimes used. In bearing orchards, the mass of velvet beans must be turned under before October 15, so that the ground may be rolled and leveled in order that the picking of the pecans may be facilitated. In plowing, the mass is first disked both ways, in order to flatten it down and it is then turned under with a disk plow or with a mouldboard plow equipped with a rolling coulter. In some orchards, both winter and summer green manures are used, but in these cases rye has so far proven to be the most satisfactory winter crop. Hairy vetch and bur clover are sometimes used, and of late the Austrian winter pea has shown promise, Fig. 62. The best winter green manure has apparently not yet been found. At present some small grain is most commonly used when a winter green manure is wanted.

The problem of the best winter green-manure crop for pecans is still engaging the attention of the better planters as well as of the student of nut culture and of soil fertility.

The great importance of growing green-manure crops in pecan orchards has recently been brought out by Skinner and Demaree in a study of the control of rosette in pecans. Two orchards in Georgia, both suffering from rosette, were observed from 1918 to 1923, various fertilizers being applied. In one orchard cover crops were grown, a legume in summer and small grain, mostly rye, in winter. In the other, corn and cotton were grown and harvested and what wild grasses grew were cut for hay and removed. In the first orchard, conditions steadily improved and in 1923 the trees produced upwards of 500 pounds of nuts per tree; in the second orchard, the rosette became steadily worse, so that the orchard was finally abandoned. The application of chemicals had no effect on the rosette and the authors say: "It is apparent that the accumulation of organic matter in the soils, whether acquired by the growing and plowing under of cover crops or by the addition of manures, composts, or debris, is beneficial to pecan trees and stimulates increased growth and yield."

In the last few years kudzu has been planted in some pecan orchards in Georgia and in Florida. The practice grew out of the desire of a Florida farmer to intercrop his young pecans with kudzu for hay, but in spite of the fact that the kudzu was cut several times in a season for hay the pecans grew so well that at eight years old they had attained the size of twelve-year old trees on clean cultivated land. Some objections have been made to the growing of kudzu in pecan orchards and sufficient time has not elapsed to make it possible to pass final judgment. The practice is of peculiar interest, however, in that it is similar to the practice often followed in the permanent plantings in the East Indies. The kudzu is not grown for green manure, though considerable quantities of organic matter are left on the ground. The primary purpose is to shade the ground, thus holding the moisture, protecting the soil from the intense summer heat, and maintaining a good tilth, Fig. 63.

Green Manuring in Citrus Groves in Florida.—The citrus soils of Florida are naturally low in organic matter and the best practice calls for the growing of a green-manure crop every year. Various crops are used, the most important of which are velvet beans, cowpeas, Crotalaria and

FIG. 63.—Kudzu as a permanent cover in a pecan orchard at Monticello, Fla. (Courtesy Charles F. Leach.)

beggarweed among leguminous crops. Often native weeds and grasses as crab grass are allowed to grow and Natal grass (Fig. 64) is also used as a cover crop.

In bearing orchards, clean cultivation is practiced from spring to June, but plowing under of green-manure crops is done in November when growth of the trees has stopped. Velvet beans are not commonly used in bearing orchards but when they are, planting is done in rows so that cultivation shall not be interfered with. The vines may be cut and drawn to one side at picking time. All cover crops in bearing orchards are cut before

FIG. 64.—Natal grass comes in naturally in Florida and is turned under for green manure. (Florida Agricultural Experiment Station.)

picking time and the cuttings left on the ground until cured, as it is believed that the turning under of fresh green material is injurious. Many crops are mowed two or three times during the season and these clippings partially decay before being turned under in November.

Beggarweed often becomes naturalized in citrus groves, springing up when cultivation ceases in June and may be cut once or twice and the cuttings allowed to decay on the surface. If the last cutting is not made too late a seed crop will still be produced. Hume gives the following analysis of beggarweed, one cutting:

	Pounds
Dry stems and leaves per acre	3489.15
Dry roots per acre	105.85
Nitrogen, stems and leaves per acre	90.71
Nitrogen, roots per acre	10.02
Nitrogen, total per acre	100.73

A species of *Crotalaria* recently introduced by the U. S. Department of Agriculture has given promise of considerable usefulness in pecan orchards and in orange groves in Florida. Stokes has reported on the quantities of organic matter and nitrogen secured from *Crotalaria striata* as compared with other annual legumes in Florida. His figures have been condensed in Table LVIII.

TABLE LVIII

WEIGHT OF AIR DRY MATTER, PERCENTAGE OF NITROGEN AND TOTAL NITROGEN PER ACRE SECURED FROM SEVERAL LEGUMES IN FLORIDA

Crop	Air Dry Matter, Pounds per acre			Nitrogen per acre			Pounds Nitrogen turned to Soil	Equivalent to 18 Per Cent Nitrate of Soda Pounds
	Tops	Roots	Total	Tops	Roots	Total		
Crotalaria striata	2186	409	2596	2.78	0.92	1.850	85.67	577
Cowpeas	1318	170	1448	2.29	1.65	1.970	51.35	346
Beggarweed *	433	187	620	1.64	1.07	1.355	15.13	102
Bunch velvet bean	914	63	977	2.51	1.48	1.995	35.07	236

* This is a much smaller yield than that reported by Hume (p. 253).

Besides its value as a soil improver, Crotalaria is said to be useful in citrus groves because it is more attractive to pumpkin bugs than are the oranges and consequently these pests leave the fruit for the Crotalaria.

Planting of Crotalaria may be done any time of the year, but preferably before February 15 and in bearing orchards it must be planted in rows so that early cultivation shall not be prevented. Crotalaria may be cut two or three times during the season, the cuttings being left on the ground as a mulch to be disked in later. The trees in a grove planted to Crotalaria are said to be healthier and to have a better green color than where this plant is not used. The use of the crop is too recent to permit of a final conclusion as to its value, but some planters have used it for six years and are constantly extending the area of grove planted to Crotalaria. *Crotalaria striata* is largely used in the extensive tung oil tree plantings newly set out near Gainesville, Fla.

Crotalaria offers great promise for the improvement of the poor Norfolk sands so common in Florida, especially on the central ridge of the state. It does well on the poorest sands, while beggarweed will not thrive unless a crop of Crotalaria has first been turned under. On these poor sands a profitable rotation can be established after Crotalaria has been allowed to produce seed before being turned under. Corn can then be planted in March, and the volunteer Crotalaria allowed to grow after the corn is laid by in July. A heavy growth carrying enough seed to reproduce will result, Fig. 65, and may be turned under in November to be followed by a winter crop of oats, thus giving two cash crops in one year with a green-manure crop to maintain productivity. In ninety to one hundred days during midsummer, when all regular farm crops have been laid by Crotalaria will make a heavy growth and add large amount of nitrogen to the soil.

FIG. 65.—*Crotalaria striata* on poor sand land in Florida. It thrives on land too poor to support beggarweed.
(Florida Agricultural Experiment Station.)

GREEN MANURING ON THE NORTH ATLANTIC SEABOARD

Green Manuring for Potatoes and Truck Crops.—Along the North Atlantic Seaboard from Viriginia to New Jersey, much of the lighter land is devoted to specialized cropping, while on the heavier lands general farming is practiced and on these heavier lands the use of a green-manure crop is infrequent. On the lighter lands, however, "cover cropping" as it is called, is common and rye, rye and vetch, vetch, and crimson clover are the crops most generally used. The early potato section of Central New Jersey, largely in Monmouth County, affords an interesting example of the use of a green-manure crop for maintaining the physical condition of the soil without regard to the question of nitrogen. These soils are naturally in good tilth and the small amount of organic matter furnished by a crop of rye not more than a few inches high keeps them in this condition, while commercial fertilizers are relied on to supply the nitrogen needed by the potatoes. Plowing must be done early and is pretty well done by the first week in March, so that a winter legume would make no growth of value. The requirements of the main crop, therefore, control the selection of a cover and green-manure crop and rye, or in rare cases, some other small grain is often the only one suitable, Fig. 66. It is claimed that a small amount of rye turned under every year has a better effect than larger amounts turned under at less frequent intervals.

FIG. 66.—Plowing under rye for early potatoes, Salem County, New Jersey.
(Photograph by J. C. Crissey.)

Another reason for the selection of rye instead of a legume in this section is the fact that an acid soil favors the production of clean potatoes, while a limed soil such as would be required for a good growth of most legumes favors the development of scab. While these two considerations, the necessity of early plowing and the desire to avoid liming on lands on which continuous potato growing is practiced, will probably always largely limit the selection of a green-manure crop to a grain, it appears from the work of App, who made an economic study of potato growing in Monmouth County, that the use of these cover crops is attended with good results. App says, "There is no area in the state where cover crops are given such careful attention as on these potato farms. It is only through this practice that the farmers are able to maintain soil fertility. In many instances the fertility and acre production appear to be increasing rather than decreasing where cover crops are skillfully used." Probably 90 per cent of the cover-cropped area in this region is in rye, some use wheat, and a few crimson clover, or mixtures of grain and clover. Wheat is said to be popular for early seedings, as it does not make so large a spring growth, which feature is believed to be advantageous when plowing is delayed. It is of interest to note that in this region experience has led to the conclusion that a moderate amount of organic matter turned under every year is more desirable than a large amount.

After analyzing the economic data from 370 potato farms, App says "From these data it appears that a system of potato growing with green manures and commercial fertilizers is more efficient in maintaining and increasing fertility in this area than is the use of live stock." Rye is also extensively used on Long Island as a green manure for potatoes.

The New Jersey Agricultural Experiment Station has been active in urging the more extensive use of cover crops, especially legumes and, in Circular I of the Division of Extension has suggested the following practice:

OUTLINE FOR COVER CROPS

Onions (from sets) followed Garden peas followed Early Sweet Corn interplanted Asparagus mterplanted Rye or Wheat stubble seeded (if moist)	in July with	1. Cowpeas * (5 or 6 pecks) or 2. Soybeans * (5 or 6 pecks)
Early Cabbage followed Early String Beans followed Early Tomatoes followed Potatoes followed Field Corn mterplanted in July or	in August with	A clover or a mixture of clovers† with winter vetch (10 to 15 pounds) and turnips (3 ounces)
Cantaloupes Cucumbers Eggplants Peppers Late Tomatoes Watermelons	Broadcast or drilled at last cultivation in August with	A clover or a mixture of clovers† with timothy (10 to 12 pounds), or winter vetch (10 to 12 pounds) and turnips (2 ounces)

* Cowpeas and soybeans are killed by frost, and may be plowed under or disked in for rye or rye and vetch, if desired, or 10 to 15 pounds of winter vetch may be sown along with the peas or beans to serve as a winter cover crop.

† In sowing red, mammoth or sweet clover or alfalfa, use 10 to 12 pounds of seed per acre. For alsike use 5 to 8 pounds, and for crimson clover, 15 to 18 pounds. After August 15, add ½ bushel of rye or wheat to clover mixtures where timothy is not sown. North of Trenton and New Brunswick clovers should be sown *before* August 15, and crimson clover should not be used.

On limed land, sweet clover is used as a green-manure crop for corn, being turned under after some spring growth has been made. This practice is still more extensive in the corn belt and will be mentioned again.

While rye is doubtless used more than any other crop, crimson clover is a favorite on the sandy lands in Delaware and eastern Maryland, and buckwheat, vetch, and cowhorn turnips are used by individual farmers or for special purposes. Buckwheat is especially useful as a catch crop to be turned under before seeding a winter cover of rye or vetch.

In this section truck growers sometimes plow down the early sweet-corn crop as soon as pulling is done and while the standing corn is still green. After a suitable interval, late spinach is planted. One farmer is reported to have sown Sudan grass in July and to have turned it under in the middle of August for a fall crop. Nearly every progressive farmer in this region seeks by one means or another to keep up the organic matter in his soil and various green-manure crops have been used for the purpose. The value of a green-manure crop has been abundantly proved by the experience of farmers and truckers in this region, but such experience is seldom recorded. However, the New Jersey Experiment Station has conducted one demonstration on light sand to sandy loam soil in Middlesex County. Sweet corn was the market crop and rye and a rye and legume mixture were the green manures used. One plat served as a check while to another 30 tons of manure per acre were applied at plowing time. All plats received commercial fertilizer at the same rate. The yields of sweet corn from the rye and legume mixture plat were greater than those from the plat receiving 30 tons of manure per acre, showing that green-manure crops can replace stable manure on this soil. The yields of sweet corn for two years as reported by Cox [47] are given in Table LXI.

TABLE LXI

YIELDS OF SWEET CORN IN COVER CROP TESTS AT JAMESBURG, N. J.
(1923 and 1925)

TREATMENT	1923 RESULTS		1925 RESULTS	
	Number of Ears	Total Yield, Pounds	Number of Ears	Total Yield, Pounds
Rye alone	450	287	439	292
Rye and legume mixture	510	394	411	299
Check. No cover crop	271	176	264	175
Manure. No cover crop	506	388	384	245

In Pennsylvania, green manuring is not practiced except by a few farmers and occasionally by potato growers or truckers. Some rotate wheat with potatoes, seeding red or sweet clover in the wheat to be turned under for potatoes, but here too the need of lime for the best growth of sweet clover and the danger of scab when land is limed limits the use of a green-manure crop. A more common practice is to turn under clover sod in the regular rotation and four-fifths of the large yields reported are said to have been secured on clover or alfalfa sod. A few have been known to sacrifice an entire year's growth of alfalfa, turning it under for green manure, but such cases are rare.

Green Manuring for Tobacco.—In parts of Connecticut and Massachusetts, there is a highly specialized tobacco culture and the problem of green-manure or cover crops has engaged the attention of growers and experiment stations for more than thirty years, but is not yet solved. For many years rye has been and is still the leading cover crop, but in 1905 the Connecticut station called attention to the advantage of hairy vetch as a nitrogen gatherer. This was found, however, to be of less value than anticipated and to-day is but rarely used. Since that time a number of cover crops have been suggested and used, among them timothy, to which attention was called by Jenkins in 1921. When seeded at the rate of half a bushel per acre it forms a thick cover and a dense root system and Jenkins estimates that "an even thick stand of timothy may contain, when plowed under, not far from 3 tons of vegetable matter, 100 pounds of nitrogen, 50 of phosphoric acid and more than 100 pounds of potash for the use of the following crop." The use of timothy is still very general among tobacco growers in the Connecticut Valley, but careful experiments have failed to show any benefit and quite frequently show a loss due to the use of timothy as a cover, and tobacco experts are advising against its use. The problem of a green-manure crop for tobacco is evidently one of extreme difficulty and involves factors not at present understood.

Green Manuring in Orchards.—The two important orchard crops east of the Appalachians from Virginia north are apples and peaches and in this territory the use of cover crops or of green-manure crops in orchards is common. In the southern portion of the territory the green-manure feature is prominent, while northward, especially in New York, the cover crop feature is of equal and perhaps of even greater importance.

In the apple section of Virginia and Maryland, the use of a green-manure crop is common and is recognized as the best practice. Cowpeas or cowpeas and sorghum are seeded by some about the middle of June and are plowed under in fall. Crimson clover is a favorite winter cover and green-manure crop in Maryland and Delaware, but farther north it is replaced by hairy vetch, rye or a mixture of the two or alsike clover is sometimes used, Fig. 67. As has already been pointed out, considerations of available labor and the acreage to be plowed will govern the relative acreage in the various crops. It is important that the acreage to be plowed in spring be not so large that part of the cover crop will become old and take too much moisture from the trees. In this section, rape and cow-horn turnips are popular with some, especially in northern New Jersey and in Pennsylvania. These crops are killed by the first severe cold and do no more than add organic matter to the soil.

FIG. 67.—Alsike clover as an orchard green-manure crop in Northern New Jersey. (New Jersey Agricultural Experiment Station.)

GREEN MANURING IN THE NORTHEASTERN UNITED STATES

This general area is the great red clover region of the United States and perhaps because of the common use of red clover in the rotations, green manures, have not been much used. Of late years, however, the better understanding of the value of sweet clover has led to its use as a green-manure crop, especially for corn, but also to some extent for potatoes and sugar beets. The use of sweet clover as a green manure for corn is probably more extensive in this region than the use of all other strictly green-manure crops put together, and the practice has been found so valuable that it is being steadily extended.

Green Manuring for Corn.—The use of sweet clover as a green manure for corn is common in northwestern Ohio where it is estimated that three-fourths of the sweet clover acreage is used in this way. It is also common in Illinois and Iowa, and is not unknown in Indiana, Missouri, and Wisconsin, and it is an interesting fact that, as a rule such use is most common in the best lands. For example, the prairie lands of northern Illinois are rich lands, and it is precisely on these lands that the turning under of sweet clover is common. In the absence of definite statistics, the acreage in sweet clover can not be given, but it is known that in one small county in southeastern Illinois alone the Farm Adviser placed orders in 1925 for more than 12 tons of sweet clover seed. It is estimated that 50 per cent of all the sweet clover acreage in Illinois is turned under for green manure, Fig. 68. In Indiana the practice is growing on the black prairie soil area where formerly a corn-oats rotation was common. Now sweet clover is used and some of the highest corn yields in this state have been produced on land on which sweet clover was turned down. The corn-oats rotation is still followed but with sweet clover in the oats and turned under for corn.

FIG. 68.—Plowing under sweet clover for green manure in Illinois.
(University of Illinois.)

The good effect of a sweet clover green-manure crop on corn has been experienced as far west as Iowa, Fig. 69, where an ever-increasing number of farmers are using sweet clover in this way. The clover is not in all cases used as a strictly green-manure crop, but when pastured during its second summer a great deal of organic matter is left to be turned under in the fall. From the standpoint of nitrogen supplied, turning under the sweet clover in the spring of the second year when 8 to 10 inches of new growth has been made is doubtless the best plan, but in some sections this puts corn-planting time rather late. When fall plowing must be done, pasturing sweet clover during the second season and turning under what the cattle do not eat is generally more satisfactory than plowing in the fall of the first year.

Fig. 69.—Plowing under sweet clover for corn in Iowa.
(Iowa State College.)

The practice followed is quite similar everywhere. Sweet clover is seeded on winter grain or with spring grain, or in the canning section of northern Illinois and in some places in Wisconsin, with peas. After the grain or pea crop has been harvested and the clover has attained some size, it may be grazed if summer pasture is wanted. In any event the spring growth of the next season is turned under about or before the first of May and corn planted. Except for the fact that sweet clover can be successfully used in this way only on soils well supplied with lime, it is very nearly an ideal green-manure crop for corn. Seeded as a companion crop in grain, no expense is involved except for seed and this is relatively cheap. The first season's growth can be utilized for pasture and thus the cost of the seed can be recovered from that source alone. It has been found that a large part of the nitrogen in the tops moves into the roots before winter and that in late fall and early spring 50 per cent or more of the total weight of the plant is in the root. The plants start growth very early in spring and even though but a small amount of top may be available for turning under, this, together with the roots, provides quite a respectable quantity of organic matter and nitrogen. Lastly, all this material decays readily and, being turned under at a time favorable to the activity of soil organisms, an abundant supply of nitrates is made available to the corn. When used in connection with lime and rock phosphate, sweet clover has been known to very materially increase the yields of corn, one canner reporting that, after the second planting of sweet clover, the yields of canning-corn were 75 per cent higher than on other farms in his neighborhood.

An outstanding example of what may be done with poor sandy land by turning under a leguminous green-manure crop is to be found in the farm of the Notre Dame University at South Bend, Indiana. In 1900, when the present farm superintendent, Brother Leo, took charge, the land was so run down that practically no crops were produced. A small yield of wheat could be secured after a year of fallow, and corn yielded nothing but a small amount of fodder. Brother Leo first applied lime and rock phosphate and by so doing got a stand of red clover. This was turned under and a rotation of corn, oats, wheat and clover was established, the entire clover growth being turned under in every rotation. One year in four is thus devoted to a green-manure crop during which a crop of red clover believed to be equivalent to two tons of hay per acre is turned under. Under this system, the land has improved so that for several years past yields of 75 to 80 bushels of corn have been harvested. At present considerable stock is kept and much manure is produced, but Brother Leo insists that without the green-manure crop once in four years the productivity of this sandy land would soon decrease. Whatever may be the need of this soil to-day, there is no question that the combination of green manure and phosphates changed a barren sandy waste into **a** productive farm.

Green Manuring for Potatoes and Sugar Beets.—Green manuring for potatoes is a not uncommon practice on many sandy or sandy loam soils of Michigan. Rye and vetch are sometimes used as a winter cover and green-manure crop and in a few cases sweet clover has been turned under in spring for potatoes. A variation of this purely green-manure practice is to pasture the sweet clover during its second season and to turn under the remaining growth in the fall for potatoes the next year. It is not possible from the data at hand to say how common this practice is, but sweet clover lends itself well to such use, the only possible objection being the fact that sweet clover will not thrive on a very acid soil and that the application of lime may encourage potato scab. However, sweet clover has been known to do well on the sandy lands of Michigan, even when the lime requirement was 1200 pounds or more per acre by the Veitch method.

In Michigan, some of the best potato growers practice a form of green manuring not, so far as known, used anywhere else except in Pennsylvania. An entire season's crop of alfalfa is sacrificed and turned under for the following potato crop. This is naturally the most expensive form of green manuring possible, but the growers claim it pays. In this method, alfalfa is first grown for from three to seven years as a hay crop, two crops a year being taken. During the last year of the alfalfa stand the first crop is cut and left on the ground as a mulch, or in some cases has been disked into the ground. In either case a second crop comes on which may or may not be lightly pastured. The following spring after the new alfalfa has grown about knee high the whole is turned under for potatoes; alfalfa is seeded again after potatoes. One grower is trying the following plan in order to get potatoes more often on the same land: plant potatoes after alfalfa as above stated, seed to sweet clover in oats the year following potatoes, harvest oats, and the next year, when the sweet clover is 12 to 18 inches high, turn it under for potatoes; follow this crop of potatoes with oats and alfalfa for three years of hay. The use of as valuable a crop as a full year's growth of alfalfa is a most striking case of green manuring and is the most expensive form of green manuring known to the writer. Some of the most successful potato growers follow it and believe it pays; they are certainly the ones who produce large yields of potatoes, the yields in one case being reported as having been 500 bushels per acre on an eleven-acre field. Supplementary fertilizers and stable manures are used in addition to the green manure.

The use of so costly a green-manure crop as an entire year's growth of alfalfa can be possible to those farmers only who command a suitable reserve of capital, but the experience of Mr. S. A. Foster, a farmer of Ingham County, Michigan, shows how a run-down sandy soil may be iprofitably farmed and improved by the use of green manures without the keeping of live stock. This farm has been in cultivation for more than sixty years and during most of that time the usual type of general farming was practiced. In common with most farms of similar nature and management, production decreased to a point where potatoes yielded 70 bushels per acre, oats 18 bushels and corn only 56 baskets of ears. In 1919, Mr. Foster determined to depend on sweet clover for soil improvement and potatoes for a money crop, and consequently sold all the cows and now maintains only the necessary number of work animals. Sweet clover was seeded with oats to which 200 pounds of acid phosphate per acre were applied and the sweet clover was turned under in early June of the next year when about 2 feet high. The potato crop was further helped by 400 pounds of acid phosphate per acre. By the use of sweet clover together with the careful utilization of all crop residues and any red clover grown and not needed for hay to feed the work animals, the productivity of this soil has been raised so that now an average of 200 bushels of potatoes, 35 bushels of oats, and 100 baskets of ear corn are produced. Besides these direct results, there has been a change for the better in that the sand no longer blows as badly as it once did, gullies that had been formed and filled in have not washed again and the crops have not suffered so badly in dry seasons. A 60-acre sandy farm has been changed from a liability into a productive farm, capable of returning a profit. The use of sweet clover in this case involves the application of marl and consequently, in dry seasons, there has been scab on the potatoes. It is possible that the owner may substitute mammoth clover for sweet clover, but this change will in no way affect the fact that by the proper use of green manures a run-down sandy soil has been made productive without the keeping of livestock. If mammoth clover is substituted and a seed crop taken, the soil management will be mainly on the basis of a crop residue system, but in years when the clover does not set seed well, the entire growth will be turned under.

Whether such a system will furnish organic matter enough for the maintenance of this light soil remains to be determined.

At this point it may be useful to emphasize the fact that legumes, while they can and if properly handled, do add nitrogen to the soil, do not increase the stores of phosphorus and potash. When the supply of either of these in any soil is so low as to prevent vigorous growth, one or both minerals must be added to give full effect to the benefits expected from the green manure. An excess of nitrogen available to the plant is of no use to it when it can not get the mineral nutrients needed. Many cases of the failure of a good growth of legumes turned under to increase yields may be traced to a deficiency in minerals without which the money crop was not able to benefit from the nitrogen added by the green manure.

The turning under of sweet clover for sugar beets is not as common as for potatoes, but the practice is not unknown in Ohio and in Michigan. Sometimes the new growth of the second spring is turned under, but, as a rule, this is rather late for sowing beets. A more common practice is to pasture during the second summer and to turn under the remainder of the growth in the fall. A rotation in which a seed crop of sweet clover is taken and beets planted the following year is also common, but such a practice, while perhaps good, contains no green-manuring features. Besides the use of a green-manure crop for corn, potatoes, and sugar beets, there are, throughout this territory, isolated cases of cover cropping and green manuring for other annual crops, but such practice is rare and sporadic.

Green Manuring for Wheat.—While wheat is not commonly green manured except as a second growth of red clover may be turned under, an unusual case of pure green manuring was practiced in western Iowa.

FIG. 70.—Dalea volunteers in wheat in Western Iowa.
(Iowa State College).

Here Dalea, a native American legume lately introduced under the name Wood's clover, from the name of the farmer on whose place the crop first came into notice, is used as a volunteer companion crop. Making a rapid growth after wheat harvest it covers the ground with a dense stand 2½ to 3 feet high and is plowed under for another crop of wheat. Seed matures before the field is plowed in the fall and a volunteer crop results in the next year's wheat. Large acreages have been plowed under for six to ten years and the yields of wheat are said by Hughes to have improved materially where Dalea has been used. Whether this crop will prove to be a good green-manure crop elsewhere can not be said at present. It is claimed that it will thrive on acid soils and if so it may become useful on soils on which sweet clover does not thrive, Fig. 70.

Green Manuring in Orchards.—Various orchard crops are grown in this area and green manuring or cover cropping is recognized as the best

FIG. 71.—Buckwheat as a green-manure crop in a peach orchard.
(U. S. Department of Agriculture.)

practice. Gould says: "The use of cover and green-manure crops is of fundamental importance and in many cases even of necessity if the orchards are to be well maintained."[1] In the sections of severe winters, the cover-crop feature is often the most important, but, as a rule, there is an effort to get the benefits of both the cover and the green-manuring features. While apple and pear orchards are sometimes left in permanent sod, peaches are always clean cultivated during the early part of the season and a green-manure crop planted after July.

In this territory winter crops are mostly used and either hairy vetch or rye alone or hairy vetch and rye mixed are practically the only crops that can survive the winters. In southern Ohio some cowpeas and soybeans are grown and turned under for soil improvement. Buckwheat is also sometimes used as a late summer green-manure crop, Fig. 71.

[1] Gould, Harris P., "Peach Growing." By permission The Macmillan Co. (Copyrighted.)

In some sections, the use of nitrogenous fertilizers has been increased and emphasis is placed on the cover-crop feature rather than on adding nitrogen. It is said that the gathering of nitrogen by legumes is of little importance in view of the fact that profits from the fruit crop warrant the free use of commercial fertilizers. All that is wanted of a cover crop under these conditions is that it shall help check growth in the fall, protect the ground and hold snow in winter and help to maintain organic matter. These functions can be performed as well by a non-legume as by a legume, sometimes better, and certainly at less expense. In such cases, part of the green-manuring features of the practice disappear, but the value of adding organic matter is fully recognized and this is, after all, the most important function of a green manure.

On Catawba Island in Lake Erie the following practice is said by Hinkle to have given good results in a peach orchard: Sweet clover is first grown for two years and plowed under 12 inches deep before trees are planted. The first year after the trees are planted, soybeans are drilled in between the rows and turned under in August, to be followed by vetch and rye, which in turn is plowed under for another crop of soybeans the next summer; this system is continued for five years. This is a case of intensive green manuring.

In Door County, Wisconsin, there is an extensive acreage in cherries and in this region Hubam or annual white sweet clover is used perhaps more than in any other single area. The seed is sown June 1 to 15 and, when the season is favorable, a growth of 5 or 6 feet maybe made; at other times the growth is sparse. The dead stalks are usually allowed to stand over winter and are worked into the soil in early spring. Some question has been raised as to the wisdom of growing a leguminous green-manure crop in late summer for fear that a late growth of the cherries might be stimulated, but time enough has not yet elapsed to make a conclusion on this point possible.

GREEN MANURING IN THE GREAT PLAINS

As a rule, green manuring is not practiced in the Great Plains and repeated trials on the part of state and Federal experiment stations have shown that the practice does not pay on dry land. The green-manure crop itself takes so much water that the following crop suffers and yields are less than after fallow. There would seem no doubt that in time the question of organic matter for these soils will become acute. This has already been recognized in other sections with limited rainfall, as eastern Washington, but an economical and practicable method for increasing the soil organic matter has not yet been worked out.

In the Red River Valley of North Dakota, the plowing under of sweet clover has come to be popular and has been attended with such good results that it is said to "make new land out of old." In some cases the clover is plowed down early in July, when 2 to 3 feet high, and the land kept fallow the remainder of the year. Wheat or rye is sown the following spring. Some farmers, however, prefer to cut the first growth for hay and to plow under the second growth early in August. By either method a very large quantity of organic matter is incorporated with the soil, and a large supply of nitrates is made available for the next year's wheat. In this section, the extent of the practice depends in part on the price of sweet-clover seed. Sweet clover thrives in the Red River Valley, a stand is easily and cheaply secured by handling the crop as a companion crop to wheat, and, when the price of seed warrants, a seed crop of sweet clover is taken.

When the price of seed is low, farmers find it more profitable to turn the clover under for green manure.

The potato growers of Minnesota have found in the white sweet clover "a 'miracle' or 'wonder-working' crop for the Red River Valley in loosening and opening up the heavy soils for potatoes and other crops."[189] In this section the physical effect of the great root growth and the addition of humus are believed to be the most important results of green manuring with sweet clover.

There are, however, within the Great Plains area some irrigated sections or sections with better rainfall, and in these some green manuring has been practiced. Such practice is confined to the use of alfalfa and sweet clover as green manures for potatoes and sugar beets. While in most cases the practice is to turn under alfalfa sod with such growth as may be present, or to turn under what sweet clover is left after the field has been grazed, there are also cases where the young sweet clover has been turned under for green manure.

This practice is most common in the irrigated sugar-beet growing section of eastern Colorado. Here the sweet clover is plowed under either in the fall of its first year or early in spring of the next season after 4 to 6 inches of growth have been made. The chief advantage of fall plowing is the possibility of earlier preparation of the ground, but care must be taken that the crop is handled right or there will be trouble with volunteer sweet clover in the beets. Immediate irrigation is essential when first season sweet clover is fall plowed. When the field is irrigated decay sets in and most of the resting buds are killed. When spring plowing is done it is advisable to irrigate either just before or just after planting the beet seed so as to hasten decay of the mass of sweet clover turned under. Good results as shown by increased yields have followed both methods. In western Nebraska second season sweet clover is spring plowed for potatoes but not for beets, since for the latter plowing must be done so early that the resting buds are not killed but volunteer badly in the beets.

FIG. 72.—After a second season's growth of sweet clover has been grazed a large amount of material remains for turning under in fall.
(U. S. Department of Agricultural

Besides this purely green-manure use of sweet clover many farmers in eastern Colorado and western Nebraska graze the sweet clover one season or take a crop of hay and turn under the late growth in fall for the next year's crop of beets. After grazing there is a large amount of material left to turn under, Fig. 72. Results from this method have been equally as good as those from the other, the only question being whether a year's grazing or a crop of sweet-clover hay is as profitable as a crop of sugar beets.

GREEN MANURING ON THE PACIFIC COAST

The conditions on the Pacific Coast vary widely, but in general they differ from those in the northeastern United States in the milder winters, which make the growing of various winter green-manure crops possible over nearly the entire area. While the crops used differ from southern California to Washington, there is a wider range of choice in winter green-manure crops than there is in the Great Lakes or corn-belt states, where sweet and red clover, hairy vetch and rye are about the only crops that can be used. The author is indebted to Profs. Sievers and Hegnauer of Pullman, Wash., to M. E. McCollum of the Western Washington Experiment Station, and to H. A. Schoth, of Corvallis, Oregon, for an account of green-manuring practices in those states.

Green Manuring in Washington and Oregon.—Washington is naturally divided into three sections, the eastern part, where rainfall is limited and green manuring is not practiced; the irrigated central valley and the moist, often wet western part. Green manuring is a common practice in the orchard sections of the irrigated part of the state. Prof. Sievers writes:

> Our orchard soils in the irrigated sections were all deficient in organic matter and nitrogen. With clean cultivation, what little organic matter was present was soon broken down, and in the course of a few years the orchardists had to resort to the growing of legume crops between the tree rows in order to supply the required nitrogen to their rapidly growing trees. The result of this is that at the present time there are very few orchards in the irrigated sections of the State of Washington that are clean cultivated. The cover drop in all cases is a legume. In most cases alfalfa has been given preferred consideration. Where vetch is grown, and by the way this crop is fast gaining favor, the residue from the crop when mature is disked into the soil early in the fall and thus reseeds itself year after year.
>
> In the case of alfalfa, the grower frequently removes one cutting of hay and then allows the growth during the remainder of the season, to be returned to the soil simply by trampling it down without any attempt to incorporate it with the soil by means of any tilling implement and some few orchardists are attempting the practice of growing alfalfa for a period of about five years, then they follow this with one year of clean cultivation and seed the orchard back to alfalfa. Where red clover has been used, there is no real plan worked out as yet and in many cases due to the shorter life of this crop, many orchards are rapidly developing a lot of June grass which, of course, does not give the results anticipated.

Vetch is commonly seeded with rye, which has proved more satisfactory than wheat, since it affords more protection to the vetch.

In western Washington, green manuring is practiced most commonly in the culture of raspberries and strawberries. For raspberries the green-manure crop of rye, wheat or common vetch or mixtures of these is seeded between the berry rows after picking in August and is turned under the following April or May. In some cases when new sandy loam soil is to be prepared for strawberries, two crops of green manures are first turned into the soil and the practice is followed with good results. There is some green manuring for crops other than berries; common vetch or vetch and rye are the usual green-manure crops and their use is said to be increasing.

In Oregon there are also semi-arid, irrigated and humid sections. In the eastern semi-arid section green manuring is naturally not practiced, while in some irrigated districts as the Hermiston, Echo and Milton Freewater districts the prevailing method is the use of crop residues, though these have much the effect of a green manure. The practice in other parts of the state is described by H. A. Schoth as follows:

The practice of using green manures is rapidly increasing throughout Oregon, especially in the Willamette Valley, Southern Oregon in the Rogue and Umpqua Valleys, and along the Columbia River, in the Hood River, the Dalles, Hermiston, Echo and Milton Freewater districts.

At present 90 per cent of the green-manure work is done in connection with orchard and small fruit farming, about 7 per cent in connection with truck farming and about 3 per cent with general farming.

The largest part, 70 per cent or more, of the green manuring is done with annual crops. In the Willamette Valley where irrigation is not practiced, except on about a half dozen truck farms, large green-manure seedings are made each year in orchard and small fruit plantings. There is very little clover or any other crop grown in these plantings during the summer, clean cultivation being practiced for moisture conservation. On fruit land, truck land and general farm land, common vetch either sowed alone or with winter oats, barley, rye or wheat is most commonly seeded, Fig 73. Some farmers sow the vetch alone but most of them use a vetch and grain combination because it is cheaper and produces more tonnage. At present some farmers are using Hungarian vetch especially in places where the land is wet or frost damage is more severe. In the upper Willamette Valley, bordering on the Columbia River, hairy or Hungarian vetch are used because the winters are often too severe for common vetch. Seedings of vetch or vetch and grain are made at about 70 pounds an acre as early in the fall as there are prospects of getting fall rains to continue growth after the seeds germinate. As there is usually enough moisture in the upper 3 inches to germinate seeds in late summer, some precaution must be taken to not seed too early and get the seed germinated with not enough moisture later to keep growth going. This usually results in most seedings being made about September 1st. Stock is kept off during the winter and if vetch is seeded, land-plaster at 50 pounds an acre is often applied early in February to increase growth. The crop is usually plowed under about March 15th. The tonnage of vetch or vetch and grain varies so much that estimates are of no value so far.

In Southern Oregon farming practices are similar to those in the Willamette Valley except about 30 per cent of the cultivated land is irrigated. On the fruit farms clean summer cultivation is practiced in most cases. Green manuring is extensively practiced and vetch either common, Hungarian, woolly podded, purple or hairy are used, seeded alone or with grain. Tangier peas have been used to a limited extent. Annual sweet clover and bur clover are used in a very limited way. The bur clover is usually volunteer. On irrigated land seedings are made in August while on unirrigated land September seedings are usually made.

Fig. 73.—Vetch seeded with oats in Clatsop County, Oregon. Vetch is the most common green-manure crop in the Pacific Northwest.
(U. S. Department of Agriculture.)

In the Dalles district green-manure crops are used for truck gardens in the river bottom or in orchards. The truck gardens and orchards are mostly irrigated. Hairy vetch is used most extensively and quite successfully although some winters it is damaged considerably. Seedings are made in September at 50 to 70 pounds an acre.

Many fruit men state that green manure is their fertility salvation. Green manuring is being practiced on all types of land. On hill land, especially the granular shotty red hill prune land, green-manure crops are especially valuable to prevent washing. In some small fruit districts green-manure crops hold snow and help protect fruit plants.

In practically all orchards, except peach and early plum, the seeding is always done before fruit picking. The fruit harvesting damages the seedings some but as the land is usually quite dry the plants soon recover.

In some orchards where green manuring has been practiced, several years it is claimed that the fertility has been increased to the point where the trees make too much wood growth so green-manure crops are now being seeded every other year.

Southern California Citrus Groves.—The greatest development of green manuring in California has been in the citrus groves of the southern part of the state and, in fact, this is perhaps as conspicuous an example of green manuring as is to be found anywhere in the United States. Citrus crops have a high acre value and their culture entails great expense, hence methods of treatment that increase returns or decrease expenses have been more carefully studied here than elsewhere. The citrus soils are, as a rule, low in organic matter and in nitrogen and, since the use of nitrogen so greatly influences yields, heavy applications have been made by means of concentrated fertilizers, manure and other bulky organic matter as alfalfa hay, lima bean straw and similar material. The constant use of concentrated fertilizers and constant clean cultivation has tended toward a bad physical condition of the soil and it has been recognized that bulky organic manures were necessary to maintain the organic matter in the soil. Discussing the need of organic matter, Vaile says: "Groves are occasionally successfully managed for as long as ten years with almost all the fertilizer applied in concentrated form. The day of reckoning is, however, sure to come. In the writer's observations there are a score or more of groves that at one time or another were looked upon as ' show places,' but that have since deteriorated rapidly through failure to recognize this principle."

It becomes, therefore, a question of how best to supply the organic matter. This can be done through manure or organic roughage or through the growing of green-manure crops. The latter method was used by some growers before 1900, but has come into general use during the past ten years. Studies on the value of different green-manure crops for citrus groves have been made by the California Agricultural Experiment Station and by the U. S. Department of Agriculture and the most important of these have been published by Mertz and by McKee.

In a study of orchard practices in the citrus industry, Vaile has brought out the point that, as measured by yields, green manures and stable manure can replace one another at least to a large extent, and that the increases from the use of green-manure crops are in inverse ratio to the amounts of manure used as shown in Table LXII from Vaile.

TABLE LXII
EFFECT OF COVER CROP ON AVERAGE YIELD OF CITRUS GROVES TREATED WITH BULKY MANURE

Manure Applied	Relative Yields	
	Without Cover Crop	With Cover Crop
Tons		
0-4.9	100	119
5-9.9	100	110
10-14.9	100	108
15-19.9	100	106

When very heavy applications of stable manure, 20-25 tons, were made, the results with and without cover crops were practically the same. It appears from this that the question of using a green-manure crop is fundamentally an economic one and that the expense of growing a green-manure crop and whatever disadvantages may be attached to its use must be offset by the cost of bulky organic manures which, to he effective must be applied in large amounts. That the use of green-manure crops to replace stable manure was found advantageous may be assumed from the increasing acreage in green manure. Vaile gives the following figures: "In the winter of 1914-15 it was estimated that less than 40,000 acres of citrus orchards were planted to green-manure crops of any kind, nearly half this acreage was planted to cereal crops. In 1915-16 approximately 67,000 were planted to leguminous green-manure crops, and in 1916-17 approximately 100,000 acres were so planted. Since 1917 there have been fluctuations in planting with an apparent upward trend."

More recently a feeling has developed among growers that an orchard in cover crop is more liable to frost injury than a clean cultivated one. That this feeling has little or no basis in fact has been shown by Young, but nevertheless insurance companies have demanded an increase in rates for frost insurance on orchards in which green-manure crops are grown and this has naturally acted as a deterrent to the planting of such crops. The reduction in acreage in green-manure crops in 1925 compared with that for 1924 appears to have been about 20 per cent. In some cases, growers have turned to a summer green manure crop, Fig. 74, but the acreage of this is limited by the amount of water available for irrigation and, owing to a succession of dry years, there has been no surplus of water and consequently summer green manuring can be practiced only in favored localities.

There is, however, reason to believe that the increase in frost insurance is not as serious a matter as may, at first sight, appear to be the case. The planting of green-manure crops is more common in the hill orchards than in those in the valley, because in the former the green-manure crop acts both as a winter cover to prevent washing and as a green manure. Frost damage is less likely in the hill orchards than in those in the valley and not only is the basic insurance rate less for the hill than for the valley orchards, but the percentage of increase by reason of the presence of the cover crop is less for the hill than for the valley orchards.

FIG. 74.—Cowpeas in a citrus grove, Southern California.
(University of California.)

Added to the above is the fact that the increased rate is effective only in case frost damage occurs, while the cover crop is present. This means that cover crops can be plowed under when frost damage threatens and in this way part of the benefit of the green-manure crop can be secured without additional expense for insurance.

The advantages of using green manures in citrus groves consist largely in improving the physical texture of the soil and in furnishing a gradually available supply of nitrogen. Doubtless too the evolution of carbon dioxide operates to make soil minerals more soluble.

The disadvantages have been stated by Coit to be:

1. The necessity of irrigation at a time when irrigation is not desirable for the trees.

2. The heavy root pruning incident to turning under a green-manure crop is not advisable when the trees are blooming and setting fruit.

3. A green-manure crop, if a host for the cottony-mold, may increase this pest in the orchard.

To these may be added the possible injury from aphids when the green-manure crop is a good host for these insects. The last-mentioned objections can, of course, be overcome by a proper selection of the green-manure crop, but the first and second must be weighed against the known need for organic matter in these soils and the cost of bulky manures. The balance will doubtless vary with soil and locality; local and temporary factors will make for an increase or a decrease in acreage, but there is no doubt in the minds of those who have most carefully studied the situation that green manuring will continue to be a standard practice in citrus groves in southern California.

The two crops most commonly used in southern California citrus groves are purple vetch and *Melilotus indica,* the combined acreage of these two constituting in 1925 between 90 and 95 per cent of the entire acreage planted to winter green-manure crops. Besides these, a limited amount of seed of white sweet clover, Hubam, and of large and small horse beans have been used. The use of Canada field peas and of common vetch, once popular, appears to have been largely abandoned in this section. The cowpea is the most important summer green manure, but some soybeans have also been used. Seeding of a winter green-manure crop is done in September or October, the best results usually following early seeding, and turning under should take place before the trees start growth in spring. This necessitates plowing not later than the end of February or early March and a green-manure crop is desired that will make the best growth by that time. For this reason, purple vetch has increased rapidly in popularity. While *Melilotus indica* has the great advantage that seed is always cheap and abundant, it falls behind purple vetch in the amount of winter growth made.

Green Manuring in Central and Northern California.—In the northern citrus section and in the deciduous orchards of the Santa Clara and Sacramento Valleys, cover cropping is a practice of more recent growth than in the southern citrus section, but it is proving popular and is being extended. Various green-manure crops are used, *Melilotus indica,* Canada peas, vetches and horse beans all being used more or less. The wild bur clover also frequently does duty as a volunteer cover crop in prune orchards.

In the Santa Clara Valley, *Melilotus indica* is extensively used, two-thirds of the acreage of green-manure crops in 1923 being reported as planted to this crop. Besides the cheapness of the seed, the fact that it escapes the attacks of aphids so common on Canada peas, horse beans and common vetch adds to its popularity.

In the Sacramento Valley the vetches are most used. Purple vetch yields the largest tonnage, but the cost of the seed is high. Common and Hungarian vetch yield less, but the cost of seed is only about one-half as much and it is believed that the regular turning of the 10 tons of green matter furnished by common vetch is enough. As illustrating the extent of the practice of green manuring in this section, it may be said that in the fall of 1925 the Sutter County Farm Bureau purchased for its members 60 tons of Hungarian vetch seed, 25 tons of purple vetch, 15 tons of *Melilotus indica,* and 2 tons of small seeded horse beans. Seeding is done in September or October if possible, and not later than November, and the crop is turned under in March or early April. In the mountain districts the hairy vetch is the only one hardy enough to endure the winters and this is usually sown with rye. Summer green manures are not much used, but Hubam sweet clover, mung beans and Dalea have proved satisfactory where there was water available. Green manuring has not yet been practiced in the rice fields in this section, though certain experiments conducted at the Rice Station at Biggs, Calif., have shown that where bur clover can be given an early start by irrigating the field in fall, the winter growth of bur clover turned under for the next rice crop has resulted in materially increasing the yield of rice. The horse bean is considered to be one of the best green-manure crops in the Sacramento Valley and would doubtless be used more extensively were it not for the large size of the seed, which materially increases the cost.

One of the chief reasons for the use of green-manure crops in the orchards of the Santa Clara Valley is to improve the physical condition of the heavy soils and this is a slow process. Immediate results can not be expected, but the regular use of green-manure crops does slowly improve tilth and this makes the soil more permeable to water. The improvement of tilth is perhaps the chief benefit derived from green-manure crops in this section and it has come to be recognized that the organic matter of the soil must be maintained.

In the walnut groves near the coast, cover crops are often used and it has been estimated that 50 per cent of the groves are so cropped. The value of the practice has not yet been fully demonstrated, however, but here too it is recognized that the use of green-manure crops improves tilth and facilitates the penetration of the irrigation water. The plants most commonly used are *Melilotus indica,* bur clover, vetches and horse beans.

New green manure and cover crops are constantly being tested by the experiment stations in various parts of the state and recently Kennedy and Madson have published a study of the mat bean *(Phaseolus aconitifolius)* which promises to be useful as a summer cover and green-manure crop. It will endure considerable drought and is reported to have produced at Kearney Park, as high as 24 tons of green matter per acre without irrigation. Because of its low, dense, prostrate and non-vining habit, the mat bean is thought to be especially promising as a green-manure crop for vineyards. On sandy soils its value as a shade crop is of importance since it prevents injury to the grapes caused by the intense radiation of heat from the hot soil.

In Southeastern California.—In southeastern California there are several hot irrigated valleys, the most extensive in area being the Imperial Valley, irrigated by water from the Colorado River. In these valleys an extensive culture of winter-grown vegetables has developed and cotton, citrus fruits and grapes are produced. Green manuring has been found advantageous and the different state and federal experiment stations have tested a variety of green-manure crops. Of these, cowpeas, especially the Brabham and Iron, are recommended as summer green manures, and the mat bean has given good results in vineyards. As winter green-manure crops, purple, common and hairy vetch, field peas, horse beans and bitter clover *(Melilotus indica)* are especially recommended. When winter vegetables are grown a summer legume is used, being raised between vegetable crops.

One of the most popular green-manuring crops in this section and one of relatively recent introduction is *Sesbania macrocarpa,* known in the Coachilla and Imperial Valleys as Sesbania or Sesban, Fig. 75. It is used as a summer green-manure catch crop to precede such winter crops as lettuce, onions, and tomatoes, and is also planted in vineyards. Its rapid growth enables it to make a large amount of material in six to ten weeks, so that it can be used between two truck crops with no sacrifice of the soil for a cropping season. It will do well on alkali land.

In the Coachilla Valley, Sesbania is seeded, usually broadcast, in June or July, and plowed under in September, after which onions are set in November. The plants of Sesbania are 6 to 8 feet high when plowed under and the crop is usually dragged down with a spike tooth harrow before plowing. Care must be taken not to allow it to become too large as it is then difficult to handle. Irrigation immediately before or after plowing and thorough compacting of the soil are necessary to the decay of the heavy mass of green material. While there are no exact data in regard to the effect of this green-manure crop on yields, an increase in onions of from 250 to 300 crates to 600 crates per acre has been reported.

FIG. 75.—Sesbania macrocarpa is a good summer green manure for Southeastern California and in parts of Mexico.
(Photograph by E. L. Garthwaite.)

Sesbania is also used in the state of Sinaloa, Mexico, and the following account has been extracted from a letter from H. Percy Meaker of Los Mochis:

I sow Sesbania dry in old tomato lands any time before our rainy season commences in July and I flood irrigate the land to bring up the seed if the rains should not be sufficient and whilst it is not necessary I sometimes hold the water on the land long enough to kill all other weeds because Sesbania will grow in water; then when there is nothing but Sesbania we take off the water and there is sufficient moisture in the soil to mature the Sesbania for turning under.

Likewise water held on the land sufficient time to kill weeds destroys cut worms and many other pests and even destroys to a certain extent fungus diseases. Hence we find we get cleaner and more abundant crops of tomatoes after using Sesbania as a green manure raised by flooding system.

It has to be turned under at the right time because the stalk gets hard very quickly and the growth is so rank that mules or horses cannot work in it so we generally break it down with tractors and disk harrows and chop it up good before we turn it under.

For us down here it is the easiest green-manure crop we can grow because it nourishes in the hot, rainy season when it is difficult to get a clean stand of cowpeas and as we sometimes lose our cowpeas by thrips we feel that Sesbania is more positive and much cheaper.

By growing Sesbania the way we do we do not have to work mules in the terrific moist heat of the rainy season to do any cultivating as we have to with cowpeas, and as Sesbania likes water just as rice does if there is abundance of water available all other weed growth can be destroyed by water.

It is important that it be not allowed to grow too large because it quickly goes out of control and becomes a great problem to turn under; this is especially so in clay soils which may be too wet to plow because of rains or too much irrigation and during the time that one might be waiting for the land to be dry enough, the Sesbania has grown out of control and one has to battle with a forest of little trees that no ordinary agricultural implement will break up and turn under successfully.

Green Manuring in New Mexico and Arizona.—In the irrigated sections of New Mexico and Arizona, green manuring is not practiced except in the orange groves near Yuma. Here Hubam, the annual white sweet clover, and purple vetch are used and a mixture of the two is often seeded. During winter and early spring the vetch makes the best growth, but in April, May and June the sweet clover outgrows the vetch and sometimes completely covers it. In these young citrus orchards, the green-manure crop is allowed to remain late, the idea being that by so doing a reserve of slowly decomposing organic matter will be accumulated for the later use of the trees. Experiments at the New Mexico Agricultural Experiment Station [81] have shown that the sweet pea makes an admirable green-manure crop, enduring more cold than any of the other winter legumes tested and successfully withstanding an extreme temperature of ten degrees below zero F. Green manuring is, however, not practiced in this state.

SUMMARY

Green manuring is practiced to a greater or less extent in all parts of the United States except on non-irrigated lands in that large area known as the Great Plains and Rocky Mountain area. Here the lack of rain makes the use of a green-manure crop impossible. Main crop green manures are rarely used in the United States and when used at all such use is temporary, the object being to get organic matter enough into the soil so that a winter legume will do well. When this object has been attained, the rotation is so arranged that a winter legume fits in and is turned under each year for the main crop. In general farming, winter legumes such as hairy vetch, and crimson clover where the winters are not too severe, or companion crops such as sweet clover, are the two classes of green-manure crops most commonly used. In orchard work both summer and winter green-manure crops are used as circumstances may require. The annual crops most generally green-manured are cotton, corn and potatoes with some green manuring for sugar beets and occasionally for small grain.

While green manuring as a definite principle of agriculture in general farming is not as yet widely established, cases are known and have been described, where by the use of green manures, sandy soil is being profitably farmed without the keeping of livestock. In these cases green manures replace stable manure and are supplemented by commercial fertilizers as may be necessary.

On the Pacific coast, green manuring is widely practiced, but the use of green manures is largely confined to orchard work. From the apple orchards of the Yakima Valley in Washington to the citrus groves of southern California green manuring is a part of the established practice.

CHAPTER XIII

GREEN MANURING IN OTHER COUNTRIES

THE practice of green manuring is much older in Europe and in Asia than it is in America and, especially in Germany, has been the subject of a great deal of study. In oriental countries where cattle are relatively scarce and where, in many places, the dung of cattle is used for fuel, there is little to spread on the fields. The use of green material in some form for digging into the soil is, therefore, an ancient practice in such countries as China and Japan. In this chapter some account will be given of the practice of green manuring and of the crops used in Europe, China, Japan, India, the East Indies and in other places where some form of green manuring is known to be in use.

Green Manuring in **Germany.**—Although Frederick the Great tried unsuccessfully in the eighteenth century to introduce the use of lupines into Germany, this plant was introduced nearly a century later and has since become the most important green-manure crop in Germany. The interest in green manuring was much advanced by the discovery of Hellriegel and Wilfarth that legumes can utilize the nitrogen of the air through the bacteria in the nodules, and there was a considerable movement in favor of farming without livestock, even on the better lands. This movement was energetically combated by Kühn, who went so far as to assert that to advise the turning under of legumes instead of feeding them was a scientific fallacy. Wagner,[306] in turn, opposed this extreme view of Kühn's and, while admitting that green manuring was especially valuable on the poor sandy lands, pointed out certain conditions, chiefly economic, that might warrant the turning under of a legume crop on the better soils rather than cutting such a crop for hay and returning the manure. By 1891 interest in the subject was so widespread that on March 18 of that year a green-manure section was established by the German Agricultural Society.

That the practice of farming without livestock and of depending on green manures for organic matter and for a part of the nitrogen requirements for a crop is still common in Germany has been shown by Hoffman [117] in a recent study of farms without livestock. Out of a total of 114 farms studied, 24 depended wholly on artificial fertilizer, 50 on green manures supplemented with artificial fertilizers, 12 on a combination of green manure, fallow and artificial fertilizers and the remainder on various combinations of artificial fertilizers, fallow and sewage, though of this group of 28 farms, 12 of them also used green manuring to some extent. The group of 50 referred to was distributed among the States of Bavaria, Baden, Württemberg, Rheinprovinz, Hannover and Brandenburg, and Hoffmann analyzes the factors that made the use of green manures desirable in different sections. These include not only physical and biological factors as the presence of poor sandy soils in Brandenburg, but easy access to markets and other economic factors, showing that the choice of green manuring or keeping stock to supply stable manure depends not only on the type of soil, but on economic considerations. On these 50 distinctly green-manure farms, 67 per cent of the cropped acreage was in grain and 20 per cent in hoed crops. On one of these farms, 50 per cent of the land was annually in a green-manure crop and the average acreage in green-manure crops on all these farms was a little less than one-third the total farm acreage. While the use of green-manuring crops is, therefore, practiced in most parts of Germany and on various soil types, its greatest extension is certainly on the sandy lands of Prussia, and on these the lupine is the chief green-manure crop.

In Germany, it is considered by the scientific men that legumes are the only "real" green-manure crops, though it is recognized that some non-legumes are used. Emphasis is placed on the nitrogen factor to the practical exclusion of all other considerations, and it is insisted that crops that do not add nitrogen to the soil have no value as green manures. This attitude is doubtless due to the fact that in Germany the development of green manuring has been greatest on the poor sandy lands. The experience in England and in America and recent studies in India do not warrant so sharp a limitation of the definition of a green-manure crop. In the United States, cases are not uncommon where the improvement or maintenance of a good physical condition of the soil is of primary importance and where the use of a non-legume is indicated. This has been shown to be also the case in India. Such cases do, indeed, also occur in Germany where farmers on the heavier lands use rape and insist that excellent results follow. From an account of a farmers' meeting as given by Ullman,[206] it is clear that their experience with rape as a green manure had been so satisfactory that they were unwilling to accept the dictum that legumes were the only agricultural plants able to take nitrogen from the air.

Three types of green-manure crops are recognized in Germany: Main crop (Hauptfrucht) green manure, subsidiary or companion (Untersaat), and stubble crop (Stoppelsaat), though some German writers combine the last two into a class called catch crops (Zwischenfrüchte). Nolte has described the manner in which each type is used and the following discussion largely follows that of this writer.

A main crop green manure requires an entire season for growth and this precludes the use of the land for a money crop. It is, therefore expensive and not to be recommended except on the poorest sands much in need of humus and nitrogen, or where the short season or lack of rain after grain harvest prevents the catch crop from getting a prompt start. The lupine is practically the only plant used when a main crop green manure is wanted and the yellow lupine is used more frequently than any other. Seeding is done from the middle of April to the middle of May and, if grain is to follow, the lupines are plowed under the middle or last of August. When a hoed crop is to follow the next season, plowing may be done in late winter or early spring.

A subsidiary crop (Untersaat) is attended with the least expense but is said to furnish less nitrogen than a main crop, and can be used only when there is enough moisture for both grain and subsidiary or companion crop. On some of the droughty sand lands, the use of such a crop is out of the question, since the well-established grain crop would use all the available moisture. When such a green manure is sown on winter grain, seeding is done in late February or early March; when with summer grain the legume is seeded with the grain or some time later. The latter is the practice with Serradella and especially with lupines. In some cases, especially when lupines are used, seeding is delayed until the grain is in blossom, in order that the legume may not injure the grain crop. Various clovers, as crimson clover, may be seeded in rye in the fall, or they may be seeded in oats when this is 3 or 4 inches high. The farmer in Germany is cautioned against the use of a subsidiary crop when insect pests which survive in the grain stubble are present. This point is of interest in the United States where the Hessian fly lives in the wheat stubble and where the presence of clover in the field makes farmers reluctant to plow such a stubble even when by doing so the damage from Hessian fly in the next crop could be diminished.

The most commonly used subsidiary crops are Serradella and the clovers, and the rate of seeding is much heavier than that in the United States. Serradella is seeded at the rate of 35 to 45 pounds per acre, alsike clover 9-14, and black medic 17-35 pounds per acre.

The last type of green manuring used in Germany is the catch crop following harvest. This can be used only when the harvest is early enough so that seeding can be done in late July or early in August. When such a catch crop is to follow grain, every effort is made to have the plow follow immediately after the mower so that the field harvested one day may be seeded the same day or the next. It is recognized that, for the growth of the catch crop, a day in July is worth a week in September. Vibrans reported on the yield of organic matter and nitrogen from vetches seeded at different dates and all cut on October 26. These data are given in Table LXIII.

TABLE LXIII
YIELD OF GREEN AND DRY MATTER AND OF NITROGEN FROM VETCHES SEEDED ON DIFFERENT DATES AND HARVESTED OCTOBER 26
(Pounds per Acre)

DATE OF SEEDING	YIELD		
	Green	Dry	Nitrogen
July 19	16,323	2678	97.1
July 20	14,263	2171	88.6
August 5	9,905	1478	53.72
August 20	5,150	920	43.1
August 31	2,773	526	24.56

By reason of the short German summer, a catch crop can follow early harvested crops only, such as winter grain, summer rye and barley and early potatoes. In exceptional cases, oats and spring wheat may ripen early enough to be followed by a catch crop. As catch crops on the lighter soils, lupines, field peas and vetches and, on better soils, peas, beans and vetches or mixtures of these various legumes are used. The use of mixtures is common and is said to be more satisfactory than the use of one legume. These mixtures are seeded at the rate of 180 to 220 pounds per acre. Crimson clover is used in some sections as a winter cover crop just as it is used in the United States. Seeded the last half of August, it makes enough growth to be plowed for potatoes by the last of April or 10th of May.

Since the success of a fall-seeded catch crop depends on the number of growing days in the fall, the use of such a crop is impossible in sections where grain ripens too late to permit of plowing and seeding by early in August. Meher states that west of a line running in a southwest-northeast direction, through eastern Brandenburg, catch crops are possible; east of that line the season is too short.

The best-known example in Germany of a large farm operated on a green-manure basis is that owned some years ago by A. Schultz at Lupitz. The farming system established by Schultz was widely known as the "L. D. system" and consisted of a combination of mineral fertilizers and green manures. Finding that his extremely poor sand needed lime and applying this he discovered that the lime had prevented a vigorous growth of the lupines on which he in great measure depended for his nitrogen. Later, he found that potash would stimulate the growth of the lupines in the presence of lime and thus, he began that system of green manuring together with liberal applications of minerals now generally used on the sandy soils of Germany. The importance of fertilizing not only the money crop but also the green-manure crop unless an abundant supply of residual fertilizer is left by the grain crop is well understood in Germany. It is recognized that legumes can make their best growth only when well supplied with potash and phosphates and can turn back to the soil a large store of nitrogen only when they make a strong growth.

Hoed crops are considered best for following a green-manure crop and potatoes or beets frequently follow lupines or Serradella. Fall-sown grain is seeded after a main crop green manure, but can not follow a catch crop. Oats and spring barley do well, but on most of the estates described in detail by Hoffman,[116] potatoes or beets follow the principal green manure crop. A number of "green-manuring farms" are also described by Trunz.

Besides the use of green manures in general agriculture, Nolte describes two special cases of interest. Green manuring is commonly practiced in forest nurseries and sometimes before the trees are to be set out. Lupines and Serradella are most commonly used and on new land, legume inoculation and mineral fertilizers are applied to insure a good growth. In some cases, strips are plowed where the trees are to be set and lupines seeded on these strips after the spruce trees are set out. Excellent results are said to follow, the growth of the trees being unusually vigorous.

In pond cultures also a legume is seeded in spring after the water has been drained off, and allowed to grow till July when the water is let in and the legumes decay in place. In this case one can scarcely speak of soil improvement and perhaps the practice is not green manuring, but it is an interesting example of the utilization of legumes. In orchards and vineyards, contrary to the practice in the United States, green manuring is seldom practiced, the reason apparently being the fear that the green manure will take too much moisture and so injure the trees or vines.

In Central European countries,, Czechoslovakia and Austria, green manuring is practiced in much the same way as in Germany and mixtures of legumes are recommended by the agricultural authorities. Dr. Antonin Nemec has kindly communicated the results of an experiment in which a mixture of one-sixth blue lupines, one-sixth horse beans, one-third East Prussian peas (Peluschke = *Pisum arvense)* and one-third common peas were seeded after rye was taken off in July. The green-manure crop was plowed under in November and potatoes planted the next year. The potatoes on the green-manured land without minerals materially outyielded those receiving minerals alone and yielded as much as those that received minerals plus a heavy dressing of stable manure. The greater vigor of the green-manured potatoes was also shown by the more abundant bloom.

Green Manuring in England.—The use of rye and buckwheat as green-manure crops was common in England before the middle of the eighteenth century, but green manuring has never become as important a practice as in Germany. During more recent years, work on the value of green manures has been done both at the Rothamsted and at the Woburn Experiment Stations, the former on heavy, the latter on light, dry land. At the Woburn station an experiment has been carried on for many years to determine the relative value of vetch and mustard as a green manure for wheat. On the Lansome field vetches and mustard have been grown and turned under and if the season permitted a second green-manure crop was grown and turned under. Wheat followed the green manure. This practice has been continued for many years with the surprising result that the yield of wheat was always higher after mustard than after vetch. In 1920, the yield following mustard was 14.2 bushels and that following vetch was 9.7 bushels. In the same year, wheat following red clover on another part of the same field yielded 27.1 bushels.

In reporting on these trials, Voelcker says that after vetch the soil was richer in organic matter and in nitrogen than after mustard and that no explanation can be given of the unexpected results. Similar trials conducted at Rothamsted and reported by Hall [93] showed that on the cold heavy soils of that station, vetch was superior to mustard as green manure for wheat. In 1910, the yield of wheat following a mustard green-manure crop at Rothamsted was 19.6 bushels, following crimson clover 30.8 and following vetch 34.3 bushels.

The more recent practice of green manuring in England has been described by Page,[226] from whose paper the following account is taken. The same three systems as used in Germany are used in England, catch crop, main crop, and subsidiary or companion crop; the catch crops are often treated as winter cover crops, as in the United States. Few farmers neglect a favorable opportunity of sowing a catch crop such as mustard between harvest and seed time. The usual practice is to fold sheep or to feed cattle on such a crop, but if that is not convenient, the catch crop is turned under for green manure.

After stating the difficulties attending the use of a green-manure crop, Page continues:

> The result is that green manuring forms a regular and essential part in the system of husbandry, only in the districts given over to special crops, such as the Fens, the Lothians, and Ayrshire, where it is extensively used after early potatoes; the market-gardening districts around Biggleswade; and the flax-growing areas of North Ireland; or in cases where the nature of the soil is such that special rotations are used, as for instance, on the London clay in Essex, where a bare fallow provides the necessary opportunity, or on the light, blowy lands of East Anglia, which can only be profitably farmed by giving one year in four to a nitrogen-gathering crop, such as lupins.

Of catch crops, Page says:

> In the famous potato districts of East Lothian and Ayrshire, rape or Italian rye grass, or a mixture of the two is sown down immediately the tubers have been lifted, in any case not later than the third week in August. Some growers then feed the green crop to the sheep, but many prefer to turn the crop in.
>
> Again, in the Holland division of Lincolnshire, and in the black lands of the Fens, mustard, rape and oats are similarly largely used by potato growers as early autumn-sown green manures, and some farmers have latterly been trying beans for the same purpose. In Essex and Suffolk, on the heavy lands of the London clay, it is a common practice to sow mustard on the bare fallow in July, and plough it in before sowing winter corn [wheat]; similarly many flax growers in County Down have got splendid results from mustard sown in August after the flax has been pulled, and turned in during January or early February.
>
> The most outstanding example of a system in the second category (main crop) is that used on the poor light glacial sands of Suffolk. This land is so poor that it scarcely repays cultivation on ordinary straightforward lines, yet by adopting a rotation such as rye, lupins, potatoes, silage crops, it is possible to make farming on this land pay well. The lupins are sown in the late spring or early summer and may be ploughed in either when in flower or seed may be gathered and the plant then turned in. The lupins do so well, even on the poorest of this land, that when turned in they give as much organic matter and nitrogen as a dressing of about 8-10 tons of farmyard manure. The use of lupins as green manure on poor sands is extending to other counties, notably Notts, where some striking results have been obtained in trials.

As for the use of companion crops, Page says:

> An example is afforded by the practice common in the market gardening districts around Biggleswade in Bedfordshire, where red or white clover is commonly sown with the corn [wheat] in spring and turned in the autumn of the new year, before potatoes. In a moist season the green matter ploughed in is often found to be as effective as a dressing of 25 tons of stable manure. Similarly, some of the growers in the Lothians sow rye grass and red clover in the spring corn [wheat] and turn it under in the following spring. The same practice has been tried in the Aberdeen district, but it is not general there, for, owing to the late harvest, green stuff in the bottom of the sheaves adds to the difficulty of drying, and after harvest it is too late for the rye grass and clover to make much growth. Of course the ploughing up of a temporary seeds ley incorporates **a** large quantity of valuable organic matter in the soil, and to this extent most arable land is green-manured at intervals. The potato growers of Lincolnshire commonly turn in the aftermath of the clover as a green manure, with good results. Where the land is left down to grass for several years, as in the Aberdeen district, and many districts in England, the sod of grass which is ploughed down is an excellent green manure, and gives so much nitrogen to the soil that no nitrogenous artificials are needed for a following oat crop, and indeed, their use is liable to cause lodging.

Besides the crops mentioned above, rye, buckwheat and thousand-headed kale are used in districts where they do well and vetches, winter beans, swedes and turnips are recommended when the crop can be left to stand through the winter.

It will be noted that many of the crops used and the practices followed in England are more like those common in the United States than is the case with crops and practices in Germany, but that the use of crucifers is far more common in England than in the United States.

Green Manuring in Holland, Belgium and Denmark.—In Holland and in Belgium lupines are also used on the sandy lands, but on the better lands red clover is largely depended upon for the maintenance of fertility. In Denmark, lupines are extensively used on sandy soils but the better soils are too valuable, and here *Medicago lupulina* is often seeded in grain and turned under in fall. Its effect is said to be equal to an application of 200 to 300 pounds of nitrate of soda per acre.[1]

Although mustard and buckwheat were formerly used, lupines have been found much more effective. Dr. Viggo Lund has kindly communicated the record of the following experiments.[1]

In a ten-year experiment the effect of green manure on the following crop was:

	Yield per Acre, Pounds	
	Grain	Straw
After fallow	726	1914
After mustard and buckwheat	810	2013
After lupines	1419	3828

In another experiment carried on from 1888 to 1914, the rotations and relative yields were:

	Relative Yields
a. Fallow, rye, potatoes, oats and barley	73
b. Lupines, rye, potatoes, oats and barley	100
c. Mustard and buckwheat, rye, potatoes, oats and barley	74

The great value of lupines under these conditions is evident.

[1] Dr. Viggo Lund, correspondence.

Green Manuring in France. [1]—The Romans introduced the use of the white lupine into Provence and here its use has continued in the vineyards from that time down. The seeds are scattered on the ground just before the grapes are gathered and are trodden in by the workers. After the grape harvest a light harrowing completes the operation and, when they have attained a sufficient height, the lupines are dug in. In the Midi, the lupine is also used, but crimson clover, horse beans, and even soybeans are sometimes sown for green manure. In general farming green manuring is rarely employed, though experiments have shown that black medic, crimson clover, red clover, and common vetch will produce increased yields. These crops, as well as the white mustard, are indeed sometimes used in preparing land for wheat. Besides these M. de Vilmorin states that gorse (*Ulex Europaeus* and *U. nanus)* and common broom *(Saroihamnus scoparius)* are in demand for manuring vines and downs and that a variety of other crops as fenugreek, Galega, and chick peas *(Cicer arietiniim)* are more or less used.

Green Manuring in Italy.[2]—While green manuring, chiefly with lupines, is a common practice in some parts of Italy it is mainly used in connection with tree or vine culture; olives are almost universally green manured. In this case, the earth is hoed around the olive trees, the area usually corresponding with the horizontal projection of the top. The seeds are sown in autumn and when the lupines are in full bloom they are cut and dug in. The practice in vineyards is similar. Wherever the lupine is used for green manuring it is a winter crop and when in bloom is cut and worked into the soil. Besides the lupine, the horse bean is used, especially on heavy clay soils, and sometimes another legume, *Galega officinalis,* is also used. Crimson clover is used and has been recommended for use in rice culture. In central Italy **a** turnip with a long oblong root is mixed with the lupines.

GREEN MANURING IN ASIA AND IN THE EAST INDIES [3]

China and Japan.—Green manuring is a very ancient practice in China and in Japan, especially in the former country, where green manures have been used for probably 3000 years. Whatever the practice may have been in ancient times, the modern Chinese farmer uses green manures almost exclusively in connection with rice culture. In these countries nothing is wasted and the value of organic matter has been so long understood that any plant material not otherwise useful is composted or applied directly as a green manure.

Robert Fortune observed the use of "trefoil or clover" as a green manure for rice on the Island of Chusan, and mentions the culture of *Coronilla* as a green manure in other parts of China, but it is not clear what the plant he calls trefoil was.

[1] The author is indebted to Prof. R. de Noter, Mougins, near Cannes, to Prof. E. Sohribaux, Director of the Seed Testing Station, Paris, and to M. Jacques de Vilmorin, Paris, for information on the present-day practice in France.

[2] The author is indebted to Dr. Mario Calvino, San Remo, Italy; and to Mr. Asher Hobson, Rome, for information regarding present-day practices in Italy.

[3] The material on tropical green manuring and green-manure crops has been taken largely from Dobbs, Mann and Hutchinson, Allan, Wright [349] and Van Helten,[299] together with the files of various periodicals devoted to tropical agriculture. Special acknowledgment is also made to the Director of the Proefstation voor Thee, for publications sent and information by correspondence in regard to green manuring in Java and Sumatra.

The best account of Japanese and Chinese present-day practice in the use of green manures available in English is to be found in King's Farmers of Forty Centuries, in which Prof. King, a trained and experienced observer, has recorded what he saw in a journey through these countries.[1] Rice is the most important summer crop in a large part of China and Japan, while sometimes a grain, mostly barley, is grown as a winter crop on the same land. No land would endure such intensive cropping for many centuries unless adequately fertilized and the Chinese and Japanese farmer uses fertilizers in large quantity. Besides the use of night soil, fish and commercial fertilizers, some form of green manuring is commonly practiced, and in both countries the plant most used for this purpose is "genge clover" *(Astragalus sinicus).* This is seeded either just before or just after rice harvest and, being a rapidly growing plant, makes a considerable amount of material, King stating that from 18 to 20 tons of green matter are produced per acre. In Japan this material is commonly cut and applied to 3 acres of rice, the stubble and roots serving as fertilizer on the land that grew the "genge." It was estimated that between 1903 and

FIG. 76.—A field of "Genge" ready for plowing under for rice in the Toyama district, Japan.
(Courtesy Prof. K. Aso, Tokyo Imperial University.)

1906, 6.8 per cent of the average area of paddy land in Japan grew a green-manure crop in the form of some legume and that in 1906, 18 per cent of the upland fields also produced a leguminous crop; while the latter was not always used for green manuring, a considerable quantity of organic matter was left as plant residues. In 1917, the total area in green-manure plants in Japan was about 1,000,000 acres. Genge is said to occupy about 65 per cent of the total area in green-manure crops in Japan, Fig. 76.

The "genge" seeded after rice harvest is allowed to grow until shortly before transplanting time, when it is turned under or composted. While the

[1] The writer has drawn freely on available literature and wishes to acknowledge especially the help kindly given by Mr. M. Yoshikawa, who has abstracted several Japanese works dealing with agriculture and from whose abstracts part of the following data are taken.

preparation and use of composts differ in details from regular green manuring, there is really not much difference between the two, except that in the compost pile the preliminary stages of decomposition are completed before the material is worked into the mud of the rice fields. The growing of rice in nursery beds and the transplanting of the rice has an advantage when green manures are used, since a month's extra time is gained. If the rice were seeded where it is to be grown and time allowed for decomposition of the green manure, the fields would need to be prepared so much earlier that only a small growth of the green-manure crop could be secured. As it is, the "genge" can grow longer and the early stages of decomposition can be completed while the young rice plants are starting in the nursery.

In some sections where a winter crop of barley is grown the same year as a summer crop of rice, soybeans are planted between the barley rows and are later turned under for rice. King says that 5290 pounds per acre of green soybeans may be produced in this way to fertilize the rice.

Besides the growing of a regular green-manure crop, both Chinese and Japanese farmers make use of wild plant material, even the grass growing on the numerous grave mounds in China being cut and utilized as green manure. Grass and weeds are cut along canal banks or in the water of the canals, and forests and hills yield their produce of vegetable matter to the industrious oriental. King states that in Japan some 2,552,741 acres of land may be cut over in this way three times each season, yielding in 1903, 7980 pounds of green matter per acre. This is all carried to the rice fields in baskets on the backs of men and women, Fig. 77, or composted, and some 10,185,500 tons are annually transported and used in this manner.

When applied directly to the rice fields, this green material is carefully laid between rows of growing rice and tramped into the mud. The amount of labor involved is tremendous and more than American farmers care to contemplate. Fortunately, American farmers have in the clovers, plants that can serve the same purpose for corn and potatoes and can be grown and applied with no more labor than is required for the production of those crops.

Besides rice, other crops also are green manured in Japan and the practice is common throughout the country. The catch-crop type of green manure is almost universally used and no opportunity is neglected to grow a crop between the main crops. Where, as in Hokkaido, barley is a summer crop, this may follow the rape of the previous year and in that case soybeans are sown after the rape and are plowed under in fall, the barley being seeded in April or May on this green-manured land. The same practice is followed in the culture of potatoes, tomatoes, etc. Where wheat or barley is the winter crop, soybeans or cow-peas are seeded late between the rows of grain and are used as green manure for the rice. In China the horse bean (*Yicia faba)* is sometimes planted in alternate rows with wheat and is turned under in June as green manure for cotton. It is also pulled up and trampled into the rice fields.

In addition to soybeans and genge, which are the most important green-manure crops in Japan, clovers, cowpeas, horse beans, lupines, peas, mung beans, rape, and radish are used, the practice varying in different districts and according to the needs of the main crop. Wherever possible, however, the land is kept working and advantage is taken of every opportunity to work some organic material into the soil.

Fig. 77.—Japanese peasants carrying green manures to the rice fields.
(From King, Farmers of Forty Centuries. Courtesy Mrs. F. H. King.)

On the Island of Formosa, two crops of rice can be grown in a year and here *Sesbania aegyptica* is a valuable green-manure plant. If intended as a green manure for the first rice crop, the Sesbania, often mixed with soybeans, is sown in the winter. If intended for the second rice crop, the Sesbania seeds are scattered among the rice plants of the first crop about the middle of June and turned under for green manure during the latter part of July.

Green manures are also used for tea gardens and, according to Harler,[98] the use of green manures has been shown to improve the quality of the tea. Serradella seeded in September and cut in June is said to have yielded 6 tons of green matter per acre at the Kanaya station; soybeans seeded in April and cut in August have yielded 2 tons of green matter. Genge is sometimes grown on the rice fields and transported to the tea gardens to be used for green manure.

Green Manuring in India.—Another Asiatic country with a very old civilization is India, and in some parts green manuring with forest leaves is an ancient practice. Systematic studies on the value of green manures and the growing of special green-manure crops is, however, of recent origin, having been undertaken by many of the agricultural experiment stations established by the Government of India. Most of this development appears to have taken place within recent years, as Knapp, writing in 1903 after a journey through India, states that inquiry at various agricultural experiment stations failed to develop a single case of green manuring. Experiments on green manuring were, however, commenced long before this, as the Agricultural Ledger of 1893 and 1897 reports on experiments in progress at the Cawnpore, Nagpur and Dumraon Experiment Stations, and it is stated that the work at Cawnpore had already been in progress for fifteen years. The work under Government auspices also appears to have been preceded by isolated experiments on the part of European planters.

At present, green manuring is practiced to some extent at least in preparing the land for rice, wheat, sugar cane, jute, tobacco, and in many of the permanent cultures, as tea, coffee and rubber, and Joachim says that "few agricultural operations have become more universally adopted and increasingly popular in India than green manuring." It must be made clear at this point that in India and in the Dutch East Indies the terms green manuring and green-manure crop are used to include crops and practices that are more nearly cover crops and cover cropping, or shade crops and shade planting than strictly green-manuring crops and green-manure practices, as understood in America. In the United States, the term "cover cropping" has come to be used to include green manuring and in the Indies the term green manuring covers also cropping primarily for protective effect, as well as the more or less permanent shade planted in tea and coffee plantations. In all these practices, soil improvement by the use of leguminous crops is, however, one of the objects sought, even if it be not always the sole or the most important object.

Since the expansion of the Agricultural Departments in India in 1905, experimental and demonstrational work has been in progress by the experiment stations in all parts of India, more especially by those in the Central Provinces, the Bombay and Madras Presidencies, Mysore, Assam, in the Island of Ceylon, and at the Agricultural Research Institute at Pusa. In the Dutch East Indies the study of green-manure crops has been made mostly with reference to permanent plantings, tea, coffee, Hevea, and Cinchona. The experiment stations in India and in Java have enriched agricultural literature with a great volume of research work on this subject.

For a brief survey of green manuring in the Indies, the subject may be considered in its relation to annual crops, as rice, wheat, tobacco and to permanent plantings.

Green Manuring for Rice.—The practice of green manuring for rice is, in India, older than that for any other crop. Dobbs, quoting Basu (1890) states that the principle of green manuring was very well understood by the raiyats, who liked to see a plentiful growth of grass in the paddy fields, and preferred the wild form of *Panicum miliaceum* to any other, merely from the fact that this was readily destroyed when preparing the land for the next crop; the grass is harrowed and trampled into the mud for the next rice crop. Leaves and twigs cut from wild shrubs are also used in many sections and these are spread green on the fields and trodden in. In some cases, trees are actually grown around every field and along the banks of water channels and such trees are lopped once in three years, the leaves and twigs being spread on the rice fields and trampled in. Molegode [208] gives a list of sixteen trees and shrubs from which the leaves and twigs are commonly cut and transported to the rice fields. He advises the use of 2000 pounds of green leaf per acre applied in two periods; the more slowly decomposing ones to be applied first. In India as in Japan, labor is cheap, but the American farmer would be staggered at the thought of cutting, transporting and spreading 2000 pounds of green material per acre for the sake of the fertilizing value of the leaves.

Such green manuring as mentioned above has, of course, no bearing on the rotation system or on the number of times the land can be cropped each year. When special green-manure crops are grown, the question of replacing a fodder or other crop arises and the economics of the situation must be considered. Such a situation is comparable to that of using a main crop green manure in the United States and is recommended by the authorities in India only when it is necessary to bring up extremely poor land. As a rule, the Indian farmer grows some legume between rice crops and this legume is harvested for fodder or for grain. There are, however, lands on which such double cropping is impracticable and on such lands a special green manure may be, and often is, used.

The interval between the first monsoon showers and the transplanting of the rice may also be utilized for producing a crop of a rapidly growing legume. For this purpose Sunn *(Crotalaria juncea)* is best, as it will make a good growth in sixty to eighty days. Sunn is also sometimes seeded among the ripening rice about fifteen to twenty days before harvest. In southern Madras, another legume, *Tephrosia pur-purea,* is used and is sown as soon after rice harvest as it is possible to work the ground, or in some sections it is sown among the rice before harvest. The entire mass is puddled into the soil and, if not well covered by plowing, the plants are pulled up and trampled in. Dhaincha *(Sesbania aculeata)* is another plant having advantages which recommend it for certain conditions and it is used as a green-manure crop to precede rice. Both dhaincha and *Tephrosia* require considerable time for growth and are used on single-crop lands only; where the land is double cropped, Sunn is used, as by this means the few weeks intervening between main crops can be utilized to produce a catch crop.

A number of experiments are recorded in the agricultural literature of India showing that the use of a green-manure crop commonly increases the yield of rice. The application of superphosphate with the green manure has been especially beneficial. In some cases, however, crop failures result and Harrison and Aiyer suggest that bad effects are experienced by using green manures on improperly drained land. In one case given by Dobbs, the failure of the rice crop after the application of a green-manure crop in 1912-13 was followed in 1913-14 by an unusually good crop. The decomposition of green manure when puddled into a rice field has been discussed on p. 108 and Harrison and Aiyer believe that the failure of a rice crop after green manuring on badly drained land may be due to the injurious decomposition products which, because of lack of drainage, are not removed from the soil.

Coleman and associates [44] have described the practice of green manuring in Mysore, and state that the leaves of trees about the fields and in the forests of the neighborhood are commonly collected for green manure. The leaves and twigs are collected from the hongay tree *(Pongamia glabra),* from *Cassia fistula, C. auriculata, Melia azadirachta, Calatropis gigantea* and from species of *Lettsomia.* These leaves are so highly regarded that the farmer often pays for the right of collection, as well as for the hauling which may have to be done a distance of 10 or 15 miles. In this State, legumes are commonly grown between rice crops, but are mostly harvested or fed off, though in some cases the entire crop is turned under. Sunn, cowpeas and gram *(Phaseolus mungo)* are the crops so used. In this State Sunn is the most important green-manure crop; cowpeas are also of some importance.

In some cases the green manure is grown in fields reserved for winter crops, and in this way, enough green material can be grown on one acre to serve for three acres of rice. Another method is to sow the green-manure crop while the rice is still standing so that the young plants will have a moist soil and the shade of the rice. After the rice is cut the green-manure crop makes rapid growth. That green manuring can be and is practiced in rice cultures in India has been shown, but it is not possible to say how extensive the practice is, especially as regards the use of special green-manure crops. From available data, this practice would appear to be more extensive in Madras Presidency than elsewhere in India.

Green Manuring for Wheat, Tobacco and Other Crops.—Green manuring for tobacco has been shown by Howard to be successful, provided the tobacco is set out at the right time. Green-manuring tobacco with Sunn is said to have become a well-established practice in Bihar. Green manuring for wheat in the Central Provinces has been shown by Allan to be successful, provided there is sufficient rainfall. Where the precipitation to be counted on after the inversion of the green manure does not exceed 10 inches, the practice is not advisable; where 12 to 16 inches may be counted on, profitable increases have been secured. It is apparent that green manuring for wheat is not as successful as for rice and results have been variable. Steward [275] has reported on a series of experiments in the Punjab, in which guara *(Cyamopsis psoraloides)* was used as a green manure. When the green manure was turned under early, better results were secured than when it was turned under late, but reasonably good increases were secured in all trials. When the guara was removed, the yields of wheat were very much less than when it was plowed in. On the whole, it appears that the plowing under of the roots and residues of a leguminous crop in connection with wheat has given more profitable returns than the turning under of the entire legume crop unless conditions were unusually favorable.

Jute is a valuable crop when the price is good and green manuring with Sunn is sometimes practiced, or when the entire Sunn crop is not turned under it is partially fed off, and the remainder is used as green manure. It is said that, while yields of Jute grown without green manuring have been 741 to 1233 pounds per acre, those after turning under Sunn have been 1728 to 1974 pounds per acre.

The practice of using green manures for sugar cane is common. In many sections leaves are gathered and "put on when the trenches are dug, the plants being laid alongside the stems of the canes and covered with the earth removed from the trenches." The use of Sunn for this purpose is also widespread. In the Bombay Presidency, it is sown in June and when 5 feet high and just about to flower is cut down and laid in the furrows as the land is plowed. Sometimes a second crop of Sunn is grown before time to plant the cane and this second crop of Sunn is also worked into the soil. In parts of the Godavari district, Sunn is sown when the cane is planted and when 2 to 3 feet high is buried beside the cane. This practice is similar to that of the sugar-cane growers of Louisiana, where they seed *Melilotus indica* and turn **it** under as a green manure. In Northwest India, sugar cane is grown after shaftal clover *(Trifolium resupinatum).* Furrows are plowed in the standing clover at proper distances apart and the cane planted on these strips. Later the remaining clover is harvested and the sod between the cane rows plowed and worked.

The use of leaf green manure and sometimes of Sunn, especially grown for the purpose, is common in connection with other special cultures and for garden crops. The cultivators of the spice gardens of the Kanara district of Bombay "depend largely on green-leaf manure, the cutting of 'soppu' or green leaves for manure from 'beta' lands assigned for the purpose, being recognized as a right of the garden owners" (Dobbs). For each acre of spice garden, nine acres of forest land are assigned from which the gardener may gather leaves for manuring.

In Java, green manuring is not common for annual crops, and in the case of sugar cane one reason for this is that the growing of cane on lands belonging to the natives is restricted by law to one year out of three, the land being, during the other two years, devoted to food crops. In Mauritius, where large holdings exist, the rule is to grow legumes as

Dolichos biflorus and *Phaseolus helvolus* as green manures between crops of sugar cane. In Delhi, tobacco is not green manured, but the land is "rested" for six years after a tobacco crop is taken.

Green Manuring in Permanent Plantations.—Permanent plantings of tea, coffee, rubber and other crops are of great importance not only in India but in the East Indies as well, and it is in connection with plantation practice that the use of the term green manuring to include cover and shade plantings is common. Such use is quite unknown in the United States or in Europe, but in the literature of the Indies, both English and Dutch, the term is regularly used in this way. The Indies are subject to heavy rainfall and the soils, especially those on which permanent plantings are made, are low in organic matter and wash readily, especially when, as is commonly the case with tea and coffee, the plantations are made on hill land. Heavy rains also produce a bad mechanical effect on the soil, causing it to bake on drying, and so destroy the tilth which is of great importance for such surface-rooting plants as coffee. Besides the need of preventing washing and the destruction of tilth, weeds must be kept down. If this is done by hoeing, great expense for labor is involved and the constant cultivation exposes the soil to all the evils of washing and beating when the heavy rains come. These reasons, as well as the need for supplying nitrogen and organic matter, early led European planters to try the planting of legumes, either as rather permanent tree plantings or as shrubs or annual crops and during the last twenty-five years work has been done by experiment stations, both Governmental and private, in studying the problem of green manuring as applied to permanent plantations. The situation as it existed in India in 1906 has been reviewed by Mann and Hutchinson for tea, and Van Helten [299] has collected data on the use of some green manures for tea, coffee, Hevea and other permanent plantings in the Dutch East Indies.

Green Manuring for Tea.—The definition of green manuring as given by Mann and Hutchinson illustrates the special viewpoint in regard to this practice in the Indies. They say of green manuring: "It consists in growing a crop, whether a tree, a bush, or an annual plant, on land in order that a commercial crop may reap advantages which its culture has bestowed upon the soil." "The object of this system of manuring, whether by the use of trees, bushes or annual plants, is to improve the soil so as to get a more luxuriant growth in the bushes under culture." While the methods of obtaining the object sought differ widely from those in use in the United States and the advantages of shade, drainage and soil cover are especially important, the ultimate object is, after all, the improvement of the soil for the benefit of the crop under culture.

The legumes first used were trees, and of these *Albizzia stipulata,* called the sau tree in India, was the earliest. This tree grows rapidly on most of the Indian tea soils and its thin leaves cast only the lightest of shade. It is a deep-rooted tree, is said to improve the drainage of tea soils, and its roots are well supplied with nodules. That the presence of the sau tree is beneficial to the tea was shown by an experiment reported by Mann and Hutchinson. In one tea garden, five lots of 100 tea bushes each were selected, three of them near sau trees, and two at a distance from the trees. The leaf from each group was carefully weighed at each picking with the following result:

Position of Bushes	Weight of Leaf rom 100 Bushes, Pounds	Weight of Leaf per Bush, Pounds
1. Near sau trees	180.0	1.8
2. Near sau trees	160.5	1.6
3. Near sau trees	180.25	1.8
4. Away from sau trees	91.0	0.9
5. Away from sau trees	70.25	0.7

The benefits derived from the sau trees are attributed largely to the action of the roots in improving drainage and fixing nitrogen which later, by the decay of the nodules, becomes available to the tea, and also in part to the abundant leaf fall. The fallen leaves are said to contain 4.97 per cent nitrogen in the dry matter. The sau trees are planted at distances of 40-60 feet and are allowed to stand for many years, the lower branches being lopped if the shade becomes too dense. Another species, *Albizzia moluccana,* is used in tea gardens in Ceylon, and *A. odoratissima* is said to be in favor in Assam. Another leguminous tree, *Erythrina lithosperma,* called the thornless dadap, Fig. 78, has been recommended for Ceylon by Wright [349] who advises that the trees be uprooted every year and new cuttings planted. Holland,[118] however, reports on some of these trees which had been allowed to attain the age of eighteen years on the tea experiment station at Peradeniya, Ceylon, and which in the last year, 1922, were lopped three times, producing 20,220 pounds of green material per acre. This author also reports that *Gliricidia maculata* has proved very successful as a shade and green-manure tree for tea at Peradeniya, giving a greater weight of green material than *Erythrina.*

Bamber gives the eight-year average production of tea from a plat (No. 149) on which the dadap was used as 1136 pounds per acre, as against 864 pounds from a plat on the same plantation but without green manure. During this time, the dadap trees had furnished 45 tons of green matter per acre, containing 822 pounds nitrogen. Writing of this same plat (149) eleven years later, Holland [119] says that "the yield and condition of these plats (144 and 149) have been adequately maintained without the application of manures, beyond the pruning mixture by maintaining a cover of dadap, lopped at regular intervals, the loppings being merely spread in the rows." The "pruning mixture" referred to consisted of 100 pounds basic slag and 60 pounds sulphate of potash forked in with the leaves from the prunings; no nitrogen was applied. Among shrubby plants, favored for planting in tea, the one most highly recommended is *Tephrosia Candida,* known as boga medeloa. This plant is used not only in Assam and other tea-growing regions of India, but has become popular in the Dutch East Indies. The advantages of boga medeloa are said to be that it will grow on poor land, has a good development of both deep and surface roots, is a good nitrogen gatherer and can be lopped at intervals, the loppings containing 3.49 per cent of nitrogen in the dry matter. The method of cultivation recommended by Mann and Hutchinson is to place a few seeds, generally three, in a place between alternate tea bushes and in alternate rows. All side branches should be lopped so as to give each bush an umbrella-shaped top. After three years the entire bush should be pulled out and buried. Van Helten [299] has reported on the use of this plant in tea gardens in Java.

FIG. 78.—The trees are "Dadaps" planted in a tea garden in Delhi. The prunings are used for green manure.
(Courtesy Director Tea Experiment Station, Buitenzorg, Java.)

Besides the trees and shrubs mentioned, certain annual crops have come into use as green manures in tea gardens, but more recently than in the case of the perennials. Annual green-manuring plants appear to be used in the Assam tea district, but not in Ceylon." In some India tea gardens a variety of *Phaseolus mungo,* called mati kalai, has come into rather extensive use and stress is laid by Mann and Hutchinson on the importance of sowing the seed at the right time. It should not be planted before or during the first part of the dry period, as during this time the tea needs all the moisture and the mati kalai itself makes but an insignificant growth. If planted just before or at the commencement of the rains, and if a thick stand is secured, the green-manure crop acts as a conserver of the nitrogen accumulated in the soil during the preceding months and the plants attain a height of 2 to 2½ feet in six to eight weeks, at which stage they should be worked into the soil. Increases in yield of tea of 13 to 22 per cent are reported from the use of this green manure.

Besides mati-kalai, other legumes have been tried or recommended by authorities in India for use in permanent plantations, among them dhaincha *(Sesbania aculeata),* which is said to grow rapidly on poor land and be ready to hoe in after sixty days. The pigeon pea *(Cajan indicium),* called arhar on raha in India, has been tried but has not been found satisfactory, and *Crotalaria striata* has been recommended by Wright for use in Ceylon.

In the publication referred to, Wright also reports on experiments with green manuring in Cacao, in rubber and in coconut plantations in Ceylon. Definite results are said to have been secured with *Vigna, Crotalaria* and groundnuts under coconuts. The value of green manuring for tea has also been emphasized by Bald, manager of a tea estate in Darjeeling, who urges green manuring "because it is much cheaper than artificial or chemical manures, it takes less labor for a given result, and it is more permanent in its results."

Green Manuring in the Malay Peninsula.—On the rubber estates of the Malay Peninsula the importance of growing legumes as cover crops, and which, in the end, become more or less definitely green-manure crops, is coming to be recognized. Mr. F. G. Spring, Agriculturist (rubber) of the Department of Agriculture at Kuala Lumpur, says, in a recent report:

> The growing of cover crops is becoming more popular each year and very many estate managers are now cultivating some form of vegetative cover. The prevention of soil erosion and thereby conserving the surface layers, is essential. The rubber tree will continue to thrive for a number of years on land which has suffered from surface wash but there comes a time when vigorous growth is no longer possible unless some means is taken to regain soil fertility. Old trees growing on badly washed soils generally have a hard dry brittle bark which is poor yielding, the bark renewal is very slow, and the trees have usually an unhealthy appearance. The improvement of such soils is best attained by the growing of vegetation. It is wise to grow a leguminous plant if possible but it must be remembered that legumes are difficult to establish on impoverished soils. *Calopogonium mucunoides* is one of the most popular plants for young clearings. *Vigna oligosperma* [V. Hosei] can be successfully grown among any age of rubber trees provided soil conditions are suitable. A cover crop which has shown great promise is *Centrosoma pubescens.* Should it not be possible to grow a leguminous cover, then it is wise to make a careful study of the local vegetation and select plants that will provide a satisfactory cover over the land and are suited to the local soil conditions.

Green Manuring on Plantations in Java.—In Java, green manuring is practiced on many of the plantations where permanent plantings are made, and this practice is said to be so satisfactory that the use of green manures is being extended. While isolated cases of experiments with green-manure crops before 1909 are recorded, general interest in the subject was not aroused until that time. Since then, various green-manure plants have been tested at the Economic Gardens in Buitenzorg and the plants considered promising have been further tested by planters in different parts of Java. According to Van Helten, *Tephrosia Candida* has proved to be the most satisfactory of these plants. It is planted between the rows of tea plants and pruned or cut from two to twelve times a year and at heights varying in most cases from 1 to 2 feet. The loppings are buried or are used as a mulch about the tea. While no figures are given showing increased yields, the results are said to have been good and the tea plants to have shown a response in better growth and more healthy appearance.

Tephrosia Candida is also used in rubber plantations in which it is used not only for the value of the humus and nitrogen, but as a ground cover to prevent soil wash and to keep down weeds. It is said to endure the shade of older rubber trees better than other legumes, and to materially improve the health and vigor of the trees; it is claimed that on poor soils rubber trees may be tapped a year sooner if *Tephrosia Candida* has been used as a green manure. Good results have followed the use of this plant on coffee plantations and it has also been tried with Cacao and Cinchona. Ettling has described the use of legumes on a coffee plantation in East Java and states that by the use of legumes and deep working of the soil a run-down plantation has been so improved that yields had risen to two and three times the yields secured from similar plantations in the neighborhood. In this case, *Tephrosia Candida, T. purpurea, Crotalaria usaramoensis,* and *C. anagyroides* were largely used. The planting of trees as *Albizzia falcata, Erythrina lithosperma* and others is also practiced in tea and coffee plantations, and among other shrubs used with tea, young coffee, Hevea and Cinchona, *Crotalaria usaramoensis,* Fig. 79, *C. anagyroides,* and *Leucaena glauca* are mentioned.

Both annual and perennial vining or creeping plants have been used in tea, coffee, rubber, oil palm, Cinchona and sisalplantations and among these special mention is made of *Indigofera endecaphylla, Vigna Hosei, Calopogonium mucunoides, Mimosa invisa* and *Shuleria vestita,* Fig. 80. The use of *Mimosa invisa* has been especially described by Van Helten

FIG. 79.—*Crotalaria usaramoensis* in an old Cinchona plantation in the Dutch East Indies at an elevation of 5000 feet.
(Courtesy Director Tea Experiment Station, Buitenzorg, Java.)

and by Van Hall as of great value in Hevea, coconut and oil palm plantings to suppress undesirable weeds, especially alang-alang *(Imperata arundinacea)* and to add humus and nitrogen to the soil. The plant is of rapid growth and its thorny branches climb over and smother all weeds. Hevea plantings are said to have been materially improved after a good stand of *Mimosa invisa* has been secured. Care must be taken that the *Mimosa* does not climb into the trees and Van Hall describes a simple and effective method of prevention. The *Mimosa* is planted between rows of trees and soon covers the ground, but as the ends of the branches reach the tree row, laborers turn back these branches, laying them over on the body of the plant. The thorny branches become entangled with the mass of growth and remain in the desired position. The value of *Mimosa invisa* on resting tobacco lands has been mentioned, p. 156. *Calopogonium mucunoides* is especially recommended by Keuchenius as a green-manure plant for rubber, oil palm and agave (sisal) plantings. The plant is a creeping legume, the prostrate branches rooting at the nodes and developing numerous nodules. It, therefore, makes an admirable ground cover forming in eight months a mass of growth 30-40 cm. thick.

It is not possible to enter further into a discussion of the numerous species tested by the experiment stations in India and in the Dutch East Indies. Descriptions of many of these will be found in the literature referred to especially in papers by Van Helten and Keuchenius, the latter alone describing sixty species. Seeds of several of the green-manure crops mentioned are advertised for sale in the tropical agricultural press.

FIG. 80.—A perennial cover of *Shuteria vestita* in an old Cinchona plantation, Dutch East Indies.
(Courtesy Director Tea Experiment Station, Buitenzorg, Java.)

GREEN MANURING IN AFRICA, OCEANIA AND IN THE WEST INDIES

Green Manuring in Africa.—In Egypt, according to Dr. M. A. El-Kelaney,[1] berseem is used regularly in the rotation and, after one to four crops of hay have been cut the residues are turned under, but it **is** never used primarily as a green-manure crop. On sandy lands lupines and peanuts are grown and the residues turned under and in upper Egypt, Gelban *(Lathyrus sativus)* is grown without irrigation, cut once for hay and turned under. While, therefore, no regular green-manuring practice is followed, the Egyptian farmer makes a point of working organic matter into the soil.

In South Africa little has been done, the country is perhaps too new, but Scherffius has called attention to the importance of green manuring for African soils and has reviewed the results of the work at various South African experiment stations.

In Natal,[2] cowpeas and velvet beans among legumes, and buckwheat, rye and rape among non-legumes, are somewhat used as green-manure crops, and the Natal authorities recommend lupines as a winter-green manure. Green manuring is practiced mostly in connection with sugar cane and is said to have become an absolute necessity in such areas. The Mauritius bean is the crop used and is allowed to grow three or four months in which time it produces 2½ to 8 tons of green matter. A green-manure crop is grown once in six to eight years.

In the Transvaal,[3] the citrus growers frequently use green manures, the field pea, cowpea, and dhal bean *(Cajan indicum),* having been used. Recently *Crotalaria juncea* has received some attention and appears to be giving good results.

[1] Correspondence.
[2] Letter from M. Edelman, Lecturer in Field Husbandry, School of Agriculture, Cedara, Natal.
[3] Letter from D. Moses, Lecturer in Field Husbandry, College of Agriculture, Potchefstroom, Transvaal.

Green Manuring in New Zealand and Australia.—In New Zealand, some experimental work has been done on the use of green manures and orchard cover crops, but the practice does not appear to be common. According to Lonsdale, most of the crops used are the same as those used in England, as white mustard, rape, lupines, vetches, red, white and crimson clover. In the tropical parts of Australia the Mauritius bean is used as a green manure in sugar-cane fields, and in West Australia the bur clover grows luxuriantly in well-fertilized orchards and "forms an excellent green manure, the plants being turned in while green and tender."[36]

The subject of green manuring in New South Wales has been fully discussed by Wenholz and by Wenholz and Broadfoot. In the sugarcane growing section, a rotation similar to that used in Louisiana is popular. An early maize is grown between cane crops and a legume, cowpeas or velvet beans, is seeded at the last working of the maize. The legume is allowed to grow for a month or more after the maize is harvested and is then turned under for another planting of cane. Some farmers also plant a legume in the maize to be turned under for another maize crop. In both citrus and deciduous orchards, the field pea is popular, though in the Murrumbidgee irrigated area the "tick bean "(*Vicia faba)* is used.

Green Manuring in the Pacific Islands.—Interest in green-manuring problems has been pronounced in all the islands of the Pacific and the West Indies on which American agricultural experiment stations have been established, though with few exceptions this work has not yet gone beyond the experimental stage. The natives of these islands do not use green manures, but in many cases do rotate non-leguminous with leguminous food crops.

Krauss [161] has pointed out the advantages of several legumes for Hawaii and other work on legumes has been done by Thompson and by Johnson, Thompson and Sahr. Green manures have been used in connection with sugar culture, but economic considerations, chiefly the necessity of constant utilization of the limited areas available and the water requirement of the crop, prevent the growing of a green-manure crop that interferes even for a short season with sugar growing. At present, therefore, green manures are not used to any extent in sugarcane culture, but pigeon peas and Para grass are both used with good results in pineapple culture in spite of the fact that the former harbors a nematode injurious to the pineapple. Krauss [163] has described two methods for using pigeon peas as a green manure. Both are used when it is desired to improve poor lands and involve the use of the ground by the green-manure crop for one to three years. In the first method the five or six months old plants of one crop are turned under with the earliest matured pods still attached. The seeds in these pods germinate and the volunteer crop resulting grows rapidly and can be turned under for some desired crop the following spring. While twelve months are needed by this method, the second method involves the use of the land by the green-manure crop for three years, and is described by Krauss as follows:

> The second method is to plant the pigeon peas in rows 5 feet apart and give them minimum amount of cultivation necessary to keep down the weeds. When the first crop of pods has matured the plants are topped to half original height, the cutoff portion being thrown between the rows. This mass with the seed pods attached gradually disintegrates forming a wonderful leaf mold, suppressing weeds and under favorable conditions may germinate enough pigeon pea seedlings to form an intercrop between the rows. This new volunteer crop as well as the plant debris from which it sprang is gradually shaded in by the new growth

on the cut-back rows. This hastens the disintegration process and the entire mass soon becomes incorporated into the surface layer of the soil. The effect of this mulch is very noticeable in connection with the increased vigor of the cut back plants. This mulching and incorporation of organic matter is repeated at six-month intervals until the soil has been brought up to the desired state of tilth and fertility. This is an extremely economical method of incorporating a large amount of organic matter within the soil especially as regards labor outlay. By actual experience we have found that approximately 40 tons of highly nitrogenous organic matter may be added to the soil in a period of three years by this method.

Besides pigeon peas, Para grass is used, especially in pineapple culture. The reason for the use of Para grass is the ease with which it is propagated, its abundance and the fact that the incorporation of a large amount of organic matter is more important than the addition of nitrogen.

In Guam also experimental work has been done to show the value of a green-manure crop.[28] It is recognized that organic matter is greatly needed and it has been shown that cowpeas and velvet beans not only '. serve as shade and cover crops to protect the soil from the hot sun during the dry season and from the heavy rains, but they add great stores of the necessary organic matter. The practice, however, has not, been taken up by the natives.

Green Manuring in Porto Rico.—In Porto Rico the use of "cover crops" was introduced by American owners of commercial citrus and other groves and a great deal of work to determine the best green-manure crops has been done by the Porto Rico Agricultural Experiment Station. Kinman has reported on some of this work and other references are to be found in various annual reports of the station. At present some of the sugar-cane growers make use of *Crotalaria juncea* and velvet beans. The cane is left three years and at the end of that time some of the planters devote a season to a green-manure crop which is turned under for cane. *Melilotus indica* is also occasionally used, but the practice of green manuring is not yet general. In the southwestern part of the island thousands of acres are said to be planted to cowpeas which are turned under prior to replanting the fields to cane.

SUMMARY

Green manuring is a more thoroughly established practice in Germany, in China and in Japan than in other countries. In Germany, few sandy land farms are operated without the use of green manures, and even on better soil types it is not uncommon to find farms without livestock. On such farms a legume green manure is usually depended upon for organic matter and for part of the nitrogen requirement. Lupines and Serradella are the crops chiefly used for green manuring. In England catch crops are largely used and here crucifers play a more important part than they do in any other country.

In the oriental countries, green manuring is an ancient practice and is most widely used for the benefit of the rice crop. For this purpose, genge is the common green manure in China and Japan, though other crops are used and large quantities of forest leaves, grasses and other waste vegetable matter are carried to the rice fields. In India, *Crotalaria juncea* and *Sesbania aculeata* are most commonly used for rice.

Green manures are also used in tea, coffee, Hevea and other permanent plantings and this practice is especially common in India and the East Indian Islands. Here the legume crop serves as cover, shade, and green-manuring crop, and it is not always possible to determine which service is the most important. Trees, shrubs and annual plants are used as shade, cover or green-manure crops. On the Islands of the Pacific and in the West Indies, experimental work on green manuring has been done, but the practice is followed to only a limited extent.

CHAPTER XIV

ECONOMICS OF GREEN MANURING

IN the previous pages it has been shown that a productive soil is more than a mass of decomposed rock fragments and that the most important single factor in making such an inert mass into soil is organic matter. It is this that supplies the humus, whose chemical nature is still not certainly known, but which profoundly affects the physical properties of the soil and furnishes both home and energy material for the microscopic life. From the organic matter, most microörganisms derive not only their energy material but their nitrogen and, in living their own lives, some of them transform a part of the nitrogen into ammonia and later others produce nitrates, from which crop plants draw their nourishment. This organic matter also makes possible the existence of other organisms which, while independent of the soil nitrogen, store up nitrogen from the air in their bodies and, in dying, enrich the soil in which they have lived. Without organic matter, most of these life processes so necessary to the growth of crop plants would be impossible and the soil would remain an inert mass of dead matter unprofitable to the farmer. The organic matter in virgin soils is there by reason of countless ages of slow accumulation from dying plants and animals, each generation of organisms adding a little and being better able to grow because of the decaying remains left behind by their predecessors.

In the growth of microörganisms organic matter is destroyed, carbon dioxide and other gases are given off, and some of the nitrates formed may later be leached out of the soil. In undisturbed soil the loss of organic matter is slow and is usually more than made up by new growth and the decay of a new generation. Up to a point, the organic matter increases in virgin soil, but as soon as such a soil is disturbed, destruction of organic matter follows rapidly. The farmer, of necessity, mines the soil through cropping and, whether or not the mineral stores in the soil are inexhaustible, the organic matter and nitrogen certainly are not. With cultivation comes an increase in microörganic life, and a more rapid decay of organic matter. The soil is exposed to washing, and leaching carries away a large portion of the nitrogen unlocked by the microflora.

A continuance of such methods leads inevitably to declining yields, slowly where soils are deep and rich, rapidly where they are poorly supplied with organic matter, but sooner or later the first flush of bountiful yields is past and lower yields must content the cultivator. Meanwhile, as population increases, land values advance, not because the land will produce more but because greater demand has increased the value of what the farmer produces. With increasing land values and declining yields the farmer is driven to consider how he may get more out of the land, and this leads to the use of fertilizers and of other methods for increasing the productivity of the soil. It was learned long ago, probably longer ago than when man first knew how to record his thoughts, that animal manures and some legumes turned into the soil would increase yields; later, rotations in which a grass or clover occupied the ground for a year or two came into use. The grass and clover sod helped to maintain the organic matter in the soil and measurably prevented the decline in productivity. Adding stable manure, legumes and grass or clover sod is largely adding organic matter. More recently, agronomists, notably the late Dr. Hopkins, have emphasized the saving of crop residues as a means of supplying organic matter. The use of stable manure, the turning under of sod and of crop residues are distinguished from the use of commercial fertilizers chiefly in the fact that by these methods the soil is directly enriched in organic matter; therein mainly lies their value.

Plant nutrients can be supplied in concentrated form, and often the use of such fertilizers must be resorted to, but alone they cannot permanently and economically maintain soil productivity.

Should Legumes be Fed or Turned Under?—A large part of the value of green manures lies, therefore, in the fact that they add to the soil organic matter and, when an inoculated legume is used, also more or less nitrogen, and their profitable utilization depends first upon the need of the soil for organic matter and nitrogen and second upon the relative economy of supplying these substances through green manures rather than through crop residues and stable manures. The question, therefore, arises, when should green manures be used, should a legume crop be fed and the manure returned or should the legume be turned under to enrich the soil?

A direct answer to this question is not possible. So much depends on conditions, any one or more of which may vary, that it would be unsafe to say with Kühn that legumes should always be fed or with others that greater advantage is to be gained by turning them under, but the elements in the problem may be examined and from this the reader may be helped to judge for himself. This method of approach is rendered the more necessary because of the scarcity of experimental data. In the following discussion, attention will be called, therefore, to some of the ways in which the economics of green manuring may be calculated without any attempt being made to show that the actual returns from green manuring have or have not been greater than from some other possible method of maintaining soil productivity.

Cost of and Returns from a Green-manure Crop.—That the turning under of a green-manure crop may be profitable is shown by the record of increased yields given in Chapter X. A practice that increases yields is a profitable one, unless indeed, the cost of the practice is too great. Naturally, the cost of a main crop green manure is higher than that of a green manure used as a companion crop or as a catch crop, and the cost of a main crop green manure can not very well be estimated here because so much depends upon the value of the crop that might have been grown in its place. Attention will, therefore, be confined to the cost of a companion crop green manure, or to a winter green manure, such as sweet clover, crimson clover, and hairy vetch. The first cost of such a green-manure crop need not be large. With crimson clover seed at 10¢ a pound and a seeding of 20 pounds per acre, the cost of this seed is $2.00 an acre; with sweet-clover seed at 12¢ a pound and a seeding of 20 pounds per acre, the cost of the seed is $2.40; in the case of hairy vetch, this cost may reach to about $3.50 per acre; the cost of seeding may be figured roughly as about 35¢ per acre, making the total first cost of these three green manures $2.35, $2.75, and $3.85 per acre, respectively. Disregarding for the moment the question of whether a more profitable use can be made of the green-manure crop by feeding it, and accepting a price of 88¢ a bushel for corn, 81¢ for potatoes, and 15¢ a pound for cotton, increased yields of 2½ bushes to 4½ bushels for corn, 3 to 4 bushels for potatoes, and 16 to 26 pounds for cotton will cover all the costs. Any excess is profit, less the cost of handling the increased yield. In this calculation no account is taken of the preparation or the plowing of the land for the green-manure crop. In the case of sweet clover used as a companion crop the ground is already prepared and there is no extra expense. Crimson clover and hairy vetch may be seeded at the last working of corn or cotton or may be put in after a crop, as potatoes, has been taken off and in such case there will be a small extra charge for the preparation of the land. When green manures have been successfully used, increased yields of 7 to 20 bushels of corn or more, and increases up to 50 or 60 bushels of potatoes and of one-third or one-half bale or more of seed cotton have been recorded, and it becomes very evident that when green manures are used as they should be used and reasonably good results are secured, a large return is insured for the initial investment in seed and labor of sowing.

Relative Fertilizer Value of Crimson Clover Fed or Turned under.— These green-manure legumes may, however, be fed and the manure returned to the land, and it has been claimed that greater net returns can be secured in this way. It is not the writer's purpose to discuss the economics of feeding cattle; the subject is too complex to be discussed here and others are more competent to do so. Attention will be called to one phase only of the subject—the probable value to the land of a given legume green-manure crop, compared with the stable manure that might be made from that legume crop. It is desirable to discuss this, since writers on agriculture not infrequently, in urging care of the stable manure, state that the manure may represent the sole profit to be derived from keeping cattle.

If a green-manure crop, such for example as crimson clover, has a stand which would yield 4000 pounds of hay, the amount of organic matter will be about 3576 pounds. If the crimson clover is turned under the organic matter, nitrogen, phosphoric acid, and potash are all returned to the soil and it may be of interest to note how much of these substances will be turned into the soil if the two tons of clover hay supposed to have been produced are fed, and the manure returned. According to Henry and Morrison, the 3576 pounds of organic matter in the clover hay will suffer a loss so that only about 1359 pounds will be recovered in the manure. Assuming that this clover hay is fed to dairy cattle, about 80 per cent of the nitrogen, 73 per cent of the phosphoric acid, and 76 per cent of the potash will be recovered in the manure. The two tons of crimson clover hay contain, according to average analyses, 80.8 pounds of nitrogen, 21.8 pounds of phosphoric acid, and 80.1 pounds of potash. When this clover is turned under, all these amounts are immediately returned to the soil, and 65 per cent of the nitrogen and all the phosphoric acid and potash may be expected to become available to subsequent crops. If, now, it be assumed that the two tons of clover hay referred to above are fed and the manure from this clover hay returned to the field on which the clover was grown, it will not be material what proportion of the nitrogen was taken from the air, and we can express the amounts received by the soil in the following tables.

TABLE LXI

ORGANIC MATTER, NITROGEN, PHOSPHORUS, AND POTASH RETURNED TO THE SOIL WHEN CRIMSON CLOVER EQUIVALENT TO TWO TONS OF HAY PER ACRE IS TURNED UNDER

Organic Matter	Nitrogen *	Phosphoric Acid	Potash
3576 lbs.	80.8 lbs. (of which 52.5 may become available)	21.8 lbs.	80.1 lbs.

If this hay is fed to dairy cows and, assuming that absolutely no loss occurs between the time the urine and dung are voided and the time that these are worked into the soil, the soil will receive the quantities shown in Table LXII.

TABLE LXII

Organic Matter	Nitrogen	Phosphoric Acid	Potash
1359 lbs.	64.6 lbs. (of which 16.15 may become available)	16.9 lbs.	60.9 lbs.

* For calculating the amount of nitrogen that may become available the availability figures given in Chapter V have been used.

However, it is well known that even with the most careful handling there are heavy and inevitable losses in handling manure. According to Lyon and Buckmann, these may be expected to reach 25 per cent of the organic matter, 45 per cent of the nitrogen, 30 per cent of the phosphoric acid, and 60 per cent of the potash, and when these figures are applied to Table LXII we have the figures expressed in Table LXIII as the amounts that may be returned to the soil in case two tons of crimson clover hay are fed, the manure carefully taken care of, and returned to the soil.

TABLE LXIII

Organic Matter	Nitrogen	Phosphoric Acid	Potash
1019 lbs.	35.5 lbs. (of which 8.88 may become available)	11.8 lbs.	24.4 lbs.

From the standpoint of valuable material returned to the soil, there is, therefore, no question but that the crimson clover used as a green manure has a much higher value than has the stable manure made from that clover. Whether, therefore, it pays to turn under a legume crop or to feed it, will resolve itself into a question as to whether it pays to feed. It is clear that when the profit of keeping livestock is to be found only in the manure, the clover or other legume would better be turned under in place. Besides the absolutely greater amounts of valuable constituents returned to the soil in this way, the farmer saves the expense of cutting, making, and hauling hay, and of hauling out the manure, besides the considerable saving of investment in stock, barns, etc. In depending on a green-manure crop rather than stable manure, the small farmer is often relieved of the necessity of keeping extra help. This may be quite an item in the farm economy.

It is not intended to dispute the value of stable manure on the farm. Good stable manure is an extremely valuable aid in maintaining crop yields, but for most farmers it is manifestly out of the question to keep cattle enough to produce manure for the entire farm, many a field does not receive as much manure as it should. To produce manure enough to put 10 tons on every acre once in five years requires, under the best conditions, the keeping of one cow, or other equivalent stock, for every 6 acres. In most cases a larger number will be needed. The argument that legumes should always be fed even though the sole profit from livestock lies in the manure is fallacious. So too is the corollary to this argument that there is no use in sowing legumes unless they can be fed.

A dairy farm, especially when the manure is well cared for, will not need green-manure crops. No doubt on such a farm the legumes can be turned into milk more profitably than into fertilizer, but the considerations outlined are of importance, especially to the small farmer on poor soil. At the Pennsylvania Agricultural Experiment Station it has been demonstrated that a rotation involving the turning under of a second crop of red clover for green manure can build up a depleted soil. Where the use of a second crop of red clover for this purpose is not practicable, another green-manure crop may be substituted. The experience of Mr. Foster, of Ingham County, Michigan, cited on page 264, shows that a green-manure crop, together with needed minerals, can replace stable manure as a means of keeping up the productivity of a light soil and at the same time relieve the farmer of a large labor expense, trouble, and risk.

Green Manures to Supplement Stable Manure.—On most farms, even where it pays to keep livestock, there is not enough manure to go round, and in such cases green manures may well be given consideration as supplementary means for increasing productivity. In such cases a comparison should be made between the cost of growing the green-manure crop and the returns likely to be secured. Wherever possible such a green manure should be a legume companion crop as the expense is least and the returns most certain. A winter green-manure crop should be second choice except in the South, where a winter cover crop should be first choice because it is valuable not alone for itself but because it will hold available nitrates and decrease washing. In Kentucky a tobacco field was found to contain, after harvest, 80 pounds of nitrogen as nitrates. Leaving the ground bare over winter will almost certainly result in the loss of this nitrogen while a cover crop, to be used later as a green manure, will save at least the most of this valuable material, equal to 500 pounds of nitrate of soda per acre. This function of a green-manure crop used as a winter cover, must not be lost sight of. In the saving of otherwise wasted nitrates it more than pays for its expense. Lastly a catch crop may be used. The catch crop will be indicated whenever, for any reason, the companion crop has failed or has not been seeded or when the kind of money crops grown are such as to leave the ground free for a few weeks only.

The cost of and the possible returns from a sweet clover, crimson clover and hairy vetch crop have already been discussed. A catch crop of soybeans need cost for seed and seeding not to exceed $1.50 to $2.00 per acre, but there will be some expense for preparing the land and for cultivating the soybeans, and it is doubtful whether a soybean green-manure crop will be profitable except as a preparation for a winter green-manure crop on very poor land. In the South, the turning under a summer legume in fall without following this with a cover crop can only result in a loss of nitrogen by decomposition and leaching. Though increased yields have followed the turning under of soybean and cowpea catch crops, it is doubtful whether the returns paid for the seed and cost of producing the catch crop.

Selling the Hay or Turning the Legume Under.—A legume crop may be cut for hay and will have a market value depending on the kind and quality of the hay. If a farmer does not have stock enough to consume his crop, he may sell the hay rather than turn under a potential money crop. He may also feel that he can purchase commercial fertilizers with the money secured for the hay and still have a profit. It is well-nigh impossible to arrive at any satisfactory figures on this point, as the value of hay varies so widely with quality and distance from market. For the sake of bringing out the points involved, however, an arbitrary example may be discussed.

Assume that a farmer has a field that would yield 1½ tons of fair crimson clover hay per acre, and that he could get $17 a ton on the farm for loose hay. His labor cost in making the hay and which may be estimated at $2.50 per ton, must first be deducted, leaving a net return of $21.75 per acre if he sells the hay. This clover should contain 60.6 pounds of nitrogen, 17.4 pounds phosphoric acid, and 60.1 pounds of potash, all of which he is selling off the farm. To buy these amounts in fertilizers would cost, at current prices, $12.12 for nitrogen, $1.09 for phosphoric acid, and $3.01 for potash, a total of $16.22. Only a part of the nitrogen in the green manure is available, however. Making due allowance for the lower availability of the nitrogen in green manures than in nitrate of soda and considering only 39.4 pounds of available nitrogen, the figure for nitrogen becomes $7.88, and the total $11.98, leaving the farmer only $9.77 to pay for the 2545 pounds of dry organic matter on which no market value can be placed, but which is known to be of great importance, especially on soils low in organic matter. An argument such as the above must, of course, not be pushed too far and circumstances may compel the sale of hay whether or not it is wise to sell. The purpose here is merely to point out that the immediate returns from the sale of hay are not indicative of what the final balance sheet for the farm will show.

On some soils farming can be carried on for some time by the liberal use of commercial fertilizers alone. The large crops made possible by the liberal use of commercial fertilizers may leave large residues and these may be sufficient to provide organic matter for some time. On heavy lands, however, the soil is likely to become hard and on light soils to be subject to drying as the organic matter content decreases. The experience with cotton growing in the South indicates clearly that the continued use of commercial fertilizers alone without replacing the organic matter makes for declining yields. On such lands it will pay better to turn the cover crop under than to sell it as hay.

A Comparison of Cost and Value of Green Manure and Stable Manure.—Lipman and Blair [73] made an illuminating calculation in 1916, and, while the prices used are not applicable to-day, the difference in the value of green manures and horse manure is so well brought out and the basis on which such comparison is made is so clearly stated that their statement will be quoted in full. Discussing the need of organic matter for the sandy soils of South Jersey, these authors say:

> The sweet potato growers, for instance, use 15 to 20 tons of horse manure per acre at a cost of $30.00 to $40.00, not including the expense of handling. The manure used by the sweet potato growers contains, on the average, 12 pounds of nitrogen, 9 pounds of phosphoric acid and 11 pounds of potash, and 450 pounds of organic matter per ton. With an application of 20 tons of manure there are supplied to the soil 240 pounds of nitrogen, 180 pounds of phosphoric acid, and 220 pounds of potash. With nitrate nitrogen at 16 cents a pound, horse manure-nitrogen is worth only 4 cents a pound. The phosphoric acid contained mostly in the undigested residue is worth at a most generous estimate, only 3 cents a pound, and the potash is also worth 3 cents a pound. Hence the nitrogen, phosphorus and potassium in the 20 tons of manure are worth $9.60, $5.40 and $6.60, respectively, or $21.60 in all. Subtracting the latter from the cost, viz., $40.00, there remains a difference of $18.40, and we may take this as the price paid for the 9000 pounds of organic matter. This organic matter could, however, be secured at a smaller cost in green manures grown at a time when the main crops are not occupying the ground, as may be seen from the following considerations. The same quantity of phosphoric acid and potash could be secured in acid phosphate and muriate of potash at a cost of 4 cents per pound (and practically all of it available) or a total cost of $16.00. Now since the quantities of horse manure noted above are applied, at most only every other year, the green manures and the horse manures should be compared on that basis. Two crops of the former (one of cowpeas and one of crimson clover) could be raised in the two seasons yielding almost as much organic matter and nitrogen as that contained in the horse manure. It should be remembered likewise, that the nitrogen in the leguminous green manure possesses a much higher rate of availability than that in horse manure.

The availability of the former is placed by Wagner at 65 (equal to dried blood nitrogen), the availability of the latter, as was already noted, at 25, as measured against nitrate-nitrogen placed at 100. The following tabulations bring out these relations more graphically:

HORSE MANURE—TWENTY TONS

	Contain, Pounds	Value	Cost
Nitrogen	240	$9.60	$9.60
Phosphoric acid	180	5.40	5.40
Potash	220	6.60	6.60
Organic matter	9000		18.40
			----.---
			$40.00

GREEN MANURE—TWO CROPS

	Contain, Pounds	Value	Cost
Nitrogen	200	$20.80	
Phosphoric acid	180	5.40	$7.20
Potash	220	6.60	8.80
Organic matter	7000		
Seed and labor			12.00
		---.---	---.---
		$32.80	$28.00

The above calculations show that the organic matter in the green manure is equivalent to 7000 pounds as against 9000 in the horse manure. There is scarcely a doubt, however, that as humus-forming material the smaller quantity of green manure is as valuable as the larger quantity of the horse manure, and mainly because of its better distribution. It will be noted likewise, that the two green-manure crops are taken to contain 180 pounds of phosphoric acid and 202 pounds of potash. This is not strictly correct, however, since but a portion of these materials was built into organic matter, the rest remaining in the soil in inorganic combinations. For the sake of comparison, the relations are taken as above, and the value of the phosphoric acid and potash in the organic combinations is placed only at 3 cents a pound. It will be seen, therefore, that this method of comparison is greatly to the disadvantage of the green manure, for no account is taken of the very considerable expense of handling the bulky horse manure nor of the manifest superiority of the green manure in permanent soil improvement as affecting the subsoil, as well as the soil. Furthermore, the amounts of organic matter and of nitrogen contained in the green manures may be very materially increased in the course of time. Notwithstanding the disadvantages to the green manure in this method of comparison, it still appears that its value of $32.80 against a cost of $28.00 leaves a balance in its favor of $4.80. In other words, the organic matter which costs $18.40 in the horse manure is obtained here for nothing, as is also a part of the nitrogen secured from the atmosphere. The difference between the two methods of farming amounts to $23.20 per acre every other year or $11.60 per acre annually, a difference that is very considerable, and may be made to mean much in farm economy. At the same time this difference is only an indication of the still greater advantages and profits that may accrue from an intelligent system of green-manuring not alone in building up thin, unproductive soils, but in maintaining and increasing the fertility of fairly productive soils."

The value given to the nitrogen in the horse manure was that established by Wagner and Dorsch and is possibly a little too low. On the other hand, the prices used are those of 1914 and some of these are lower than current prices to-day. This difference in prices is especially marked in the case of stable manure for which the Jersey trucker of to-day pays $4.00 per ton with an additional charge of 50¢ to $1.00 a ton for hauling and spreading. The 20 tons of manure mentioned by Lipman and Blair would cost the farmer between $90 and $120.00, while the cost of the two green-manure crops is not very much higher to-day than it was in 1914. In the Norfolk trucking region the cost of manure is even higher, averaging last year about $6.50 per ton on the farm.

Cost and Value of a Sweet-clover Green-manure Crop as Compared with Stable Manure.—In many parts of the corn belt sweet clover is coming into use as a green manure for corn and it is possible to get some idea of the relative cost and value of such a crop as compared with barnyard manure, at least as concerns the nitrogen.

Cost of putting in sweet clover per acre	$2.75
Cost of hauling 15 tons manure per acre	7.50
Nitrogen in sweet clover tops and roots per acre	264 pounds, of which two-thirds may be figured as having been secured free from the air, or 176 pounds
Nitrogen in 15 tons average barnyard manure	150 pounds

The figures for the quantity of nitrogen per acre in sweet clover are taken from Whiting and Richmond,[136] Table 7, and to these, which represent nitrogen in tops only, has been added the amount of nitrogen in roots estimated to be 95 per cent as much as that in the tops. The figures show that by sowing sweet clover at a cost about one-third that of hauling manure a larger quantity of nitrogen may be secured than is furnished by the manure. Furthermore, this green-manure nitrogen is more available than that in stable manure and Whiting and Richmond showed that sweet clover turned under produced more nitrates during June, July, and August than was furnished by 19 tons barnyard manure.

The 15 tons barnyard manure mentioned above will contain some potash and phosphoric acid, while any turned into the soil with the sweet clover was first taken from the soil and hence is not an addition. Attention should, however, be called to the fact that some of the minerals in the sweet clover were brought from depths not commonly reached by crops and that these amounts are left in the surface layer which is enriched to that extent. Ignoring this, however, the manure and sweet clover may be compared in the following figures. According to average analyses the 15 tons of barnyard manure will contain 150 pounds of potash, 75 pounds of phosphoric acid and 150 pounds of nitrogen. The potash and phosphoric acid will be worth at current prices $12.19, while the nitrogen, if all available, would be worth $30.00. It is not all available, however, and the portion (25 per cent) of this nitrogen that may be expected to be available to the next crop will have a value of only |7.50.

The nitrogen in young sweet clover is known to be very available, probably very much more so than that of the average green manure, but using the same figure used before (65 per cent) we find that the 176 pounds of nitrogen taken from the air by the sweet clover will have a value of $22.88. The balance between barnyard manure and sweet clover may then be expressed as shown on page 323.

The net balance of cost and value in terms of fertilizer ingredients is thus decidedly in favor of the sweet clover even when considering no cost for the manure except that of hauling and including in the value of the sweet clover only the available portion of the nitrogen secured from the atmosphere.

Value of available nitrogen in 15 tons barnyard manure	$7.50
Value of potash and phosphoric acid in 15 tons barnyard manure	12.19

	$19.69
Less cost of hauling	7.50
	--------
	net $12.19
Value of available part of 176 pounds of free nitrogen in sweet clover	$22 88
Less cost of seeding	2.75
	--------
	net $20.13

The examples above discussed give point to the statement that the turning under of a legume green-manure crop is not necessarily wasteful. If a legume can be better used by being turned into animal products it should be so used, but unless a profit from such use can be expected the farmer would better turn the legume under. Used in that way it will more than pay for itself in the increased yields of subsequent crops.

SUMMARY

The value of a green-manure crop lies principally in the fact that by its use organic matter and, when a legume is used, additional nitrogen are added to the soil with a consequent improvement in soil tilth and in the quantity of available plant-food material. There are, however, many minor benefits to be derived from green manuring as outlined in Chapter VIII. The relative importance of the benefits from green manuring will vary with soil and climatic conditions as well as with the type of farming carried on. The economy of using green manures is therefore largely a local problem and will depend on local and farm management factors. If keeping livestock is profitable, legumes can be better utilized for feed than for fertilizer, but when the sole profit in keeping live stock consists in the manure the legumes can be more profitably turned under than fed at a loss. In this way overhead and capital investment are both reduced.

In this chapter some of the factors entering into the problem of the economics of green manuring have been discussed and it has been shown that the idea that the acreage in legumes should be limited to that needed for feed or for sale is a fallacy. Legumes of many kinds, especially when grown as companion crops or as winter cover crops, can profitably be grown for green manuring alone and thus supplement the usually inadequate supplies of stable manure.

BIBLIOGRAPHY OF TEXT REFERENCES

1. ADINARYANA RAO, K. A preliminary account of symbiotic nitrogen fixation in non-leguminous plants with special reference to *Chomelia asiatica. Agr. Jour. India* 18: 132-143. 1923.
2. ADINARYANA RAO, K. Organic manures and availability of plant food. *Jour. Madras Agr. Students' Union* 12: 443-446. 1924.
3. AGEE, ALVA. Crops and methods for soil improvement. The Macmillan Co., New York. 1912.
4. ALBRECHT, WILLIAM A. Viable legume bacteria in sun-dried soil. *Jour. Amer. Soc. Agron.* 14: 49-50. 1922.
5. ALLAN, ROBERT G. Green manuring in the Central Provinces. *Agr. Jour. India* 10: 380-394. 1915.
6. ALLEN, RICHARD. Brief compend of American agriculture. New York. 1846.
7. ALWAY, FRED J., and J. R. NELLER. A field study of the influence of organic matter upon the waterholding capacity of a silt-loam soil. *Jour. Agr. Research* 16: 263-278. 1919.
8. ALWAY, FRED J., and R. M. PINCKNEY. The nitrogen content of inoculated and uninoculated alfalfa plants. *Nebr. Agr. Expt. Sia. 23rd Ann. Rpt.* 33—34. 1910.
9. AMES, J. W., and C. J. SCHOLLENBERGER. Liming and lime requirement of soil. *Ohio Agr. Expt. Sta. Bul.* 306. 281-396. 1916.
10. ANDREWS, E. A. Notes on insect pests of green manures and shade trees. *Indian Tea Asso., Sci. Dept. Quart. Jour.* 57-62. 1915: 18-21. 1916.
11. ANONYMOUS. Soils and crops. Recent progress in solving some farm problems of Illinois. *Ill. Agr. Expt. Sta. 37th Ann. Rpt.* 25-27. 1924.
12. ANONYMOUS. Erosion costs farmers $200,000,000 annually. *Off. Rec. U. S. Dept. Agr.* 5(46): 1-2. 1926.
13. App, FRANK. Farm profits and factors influencing profits on 370 potato farms in Monmouth Co., N. J. *N. J. Agr. Expt. Sta. Bul.* 294. 1916.
14. ARND, TH. Über schädliche Stickstoffumsetzungen in Hochmoorboden als Folge der Wirkung starker Kalkgaben. *Landw. Jahrb.* 47: 371-442. 1914.
15. ARNDT, F. Bodenhygiene und Gründungung. *Milt. Oekonom. Gesell. Sachsen.* 29-70. 1912-13.
16. ARNY, A. C, and F. W. MCGINNIS. Methods of applying inoculated soil to the seed of leguminous crops. *Jour. Amer. Soc. Agron.* 13: 289-303. 1922.
17. ARNY, A. C, and F. W. MCGINNIS. The relative value of the annual white, the biennial white and the biennial yellow sweet clover. *Jour. Amer. Soc. Agron.* 16: 384-396. 1924.
18. ARNY, A. C, and R. W. THATCHER. The effect of different methods of inoculation on the yield and protein content of alfalfa and sweet clover. *Jour. Amer. Soc. Agron. 7:* 172-185. 1915; 9: 127-137. 1917.
19. ATWATER, W. O. On the acquisition of atmospheric nitrogen by plants. *Amer. Chem. Jour.* 6: 365-388. 1885.
20. ATWATER, W. O., and C. D. WOODS. The acquisition of atmospheric nitrogen by plants. *Conn. (Storrs) Agr. Expt. Sta. 3rd Ann. Rpt.* 12-56. 1890.
21. BAKER, O. E. Land utilization in the United States: Geographical aspects of the problem. *Geogr. Rev.* 13: 1-26. 1923.
22. BAL, D. V. Studies on the decomposition of some common green manuring plants at different stages of growth in the black cotton soil of the Central Provinces. *Agr. Jour. India* 17: 133-151. 1922.
23. BALD, CLAUDE. Green manuring on tea estates. *Agr. Jour. India* 9: 182—189. 1914.
24. BAMBER, M. K. Green manuring at the Experiment Station, Perideniya. *Dept. Agr. Ceylon Bui.* 9: 119-134. 1914.
25. BAXTER, F. C. The relation of organic matter and the feeding power of plants to the utilization of rock phosphate. *Soil Sci.* 12: 21–41. 1921.
26. BOLTZ, G. E. Loss of organic matter in clover returned to the soil. *Jour. Amer. Soc. Agron.* 10: 210-214. 1918.

27. BOTTOMLEY, W. B. The effect of organic matter on the growth of various water plants in culture solution. *Ann. Bot.* 34: 353-365. 1920.
28. BRIGGS, GLEN. Leguminous crops for Guam. *Guam Agr. Expt. Sta. Bul.* 4. 1922.
29. BRISCOE, CHARLES F., and H. H. HARNED. Bacteriological effects of green manure. Study No. II. *Miss. Agr. Expt. Sta. Bul.* 185: 1-18. 1918.
30. BROWN, P. E. Some bacteriological effects of liming. *Iowa Agr. Expt. Sta. Research Bul.* 2. 1911.
31. BROWN, P. E. Bacteriological studies of field soils. I, The effect of liming. *Iowa Agr. Expt. Sta. Research Bul.* 5. 1912.
32. BROWN, P. E., and J. H. STALLINGS. Inoculated legumes as nitrogenous fertilizers. *Soil Sci.* 12: 365-407. 1921.
33. BURGESS, PAUL S. The yield and mineral content of crop plants as influenced by those preceding. *R. I. Agr. Expt. Sta. Bul.* 198. 1924.
34. CAMERON, FRANK K. A comparison of the organic matter in different soil types *Jour. Amer. Chem. Soc.* 27: 256-258. 1905.
35. CARD, FRED W. Bush fruits. *R. I. Agr. Expt. Sta. Bul.* 91. 1903.
36. CARNE, W. M., C. A. GARDNER and A. B. ADAMS. Trefoil or Burr trefoil. *Jour. Dept. Agr. West. Aust.* 2: Ser. 2: 385. 1925.
37. CATES, H. R. Humus or vegetable matter and soil fertility. *U. S. Dept. Agr. Weekly News Letter* 1 (39). May 6, 1914.
38. CHAMBLISS, CHARLES E., and MITCHEL JENKINS. Experiments in rice production in southeastern Louisiana. *U. S. Dept. Agr. Bul.* 1356. 1925.
39. CLARK, NORMAN A., and EMERY M. ROLLER. "Auximones" and the growth of the green plant. *Soil Sci.* 17: 193-198. 1924.
40. CLAUSEN, H. Wirkung des Rotklees als Vorfrucht. *Deut. Landw. Presse* 21: 633. 1894.
41. COE, H. S. Sweet clover; Growing the crop. *U. S. Dept. Agr. Farmers' Bul.* 797. 1917.
42. COIT, JOHN E. Citrus fruits. The Macmillan Co., New York. 1917.
43. COLEMAN, DAVID A. Environmental factors influencing the activity of soil fungi. *Soil Sci.* 2: 1-65. 1916.
44. COLEMAN, LESLIE C, B. NARASIMHA IYENGAR and N. SAMPATIENGAR. Green manuring in Mysore. *Mysore Dept. Agr. Bul,* Gen. Ser. 1. 1912.
45. CONNER, S. D., and H. A. NOYES. Natural carbonates of calcium and magnesium in relation to the chemical composition, bacterial content and crop-producing power of two very acid soils. *Jour. Agr. Research* 18: 119-125. 1919.
46. Cox, HERBERT R. Winter cover crops for New Jersey. *N. J. Agr. Col. Ext. Bul.* 38. 1924.
47. Cox, HERBERT R. Jamesburg tests show value of cover crops for manure. *N. J. Agr.* 8(5): 6. 1926.
48. DARWIN, CHARLES. The formation of vegetable mould through the action of worms, with observations on their habits. D. Appleton Co., New York. 1890.
49. DICKSON, ADAM. The husbandry of the ancients. G. Robinson, London. 1788.
50. DOBBS, A. C. Green manuring in India. *Acr. Research Inst. Pusa Bul.* 56. 1916.
51. DORYLAND, C. J. T. The influence of energy material upon the relation of soil microörganisms to soluble plant food. *N. D. Agr. Expt. Sta. Bul.* 116. 1916.
52. DRECHSLER, CHARLES. Morphology of the genus Actinomyees. *Bot. Gaz.* 67: 65-83; 147-168. 1919.
53. DRINKARD, A. W., JR. *Va. Agr. Expt. Sta. Ann. Rpt.* 1916-1917: 21. 1918.
54. DUGGAR, J. F. Experiments with crimson clover and hairy vetch. *Ala. Agr. Expt. Sta. Bul.* 96. 1898.
55. DUGGAR, J. F. Winter pasturage, hay and fertility afforded by hairy vetch. *Ala. Agr. Expt. Sta. Bul.* 105. 1899.
56. DUDLEY, F. L., and M. M. JONES. Effects of soil treatment upon the draft of plows. *Soil Sci.* 21: 277-288. 1926.
57. DVORAK, JOSEF. Studien über die Stickstoffanhäufung im Boden durch Mikroorganismen. *Ztschr. Landw. Versuchen. Osterr.* 15: 1077-1121. 1913.

58. DYER, BERNARD. Results of investigations on the Rothamsted soils. *U. S. Dept. Agr. Off. Expt. Stas. Bul.* 106. 1902.
59. EAST, E. M. Future food prospects. *World Agr.* 2: 130-132. 1921.
60. ELIOTT, JARED. Essays upon field husbandry in New England, 1747. Papers for 1811, communicated to Mass. Soc. for Promoting Agriculture. Boston. 1811.
61. ENGBERDING, DIEDRICH. Vergleichende Untersuchungen über die Bakterienzahl im Aekerboden in ihrer Abhängigkeit von äusseren Einflüssen. *Centbl. Bakt. Par. u. Infektionskrankheiten.* 2 Abt. 23: 569-642. 1909.
62. ETTLING, CAKL. Der Einfluss von Leguminosen auf Boden und Ernte in den Kaffeekulturen der Pflanzung Soemer Asin. (Java). *Der Tropenpflanzen* 28: 228-241. 1925.
63. FABER, F. C. VON. Das Erbliche Zusammenleben von Bacterien und tropischen Pflanzen. *Jahbr. Wiss. Bot. 51; 285-375.* 1912.
64. FABER, F. C. VON. Die Bakteriensymbiose der Rubiaceen. *Jahrb. Wiss. Bot.* 54: 243-264. 1914.
65. FELLERS, C. E. The effect of inoculation, fertilizer treatment and certain minerals on the yield, composition and nodule formation of soy beans. *Soil Sci.* 6: 81-119. 1918.
66. FORTUNE, ROBERT. Three years' wanderings in the northern provinces of China. Ed. 2. John Murray, London. 1847.
67. FEAPS, G. S. Losses of moisture and plant food by percolation. *Tex. Agr. Expt. Sta. Bul.* 171. 1914.
68. FREAR, WM., and ENOS H. HESS. Effects of different systems of manuring upon the amount and quality of humus in the soil. *Penn. Agr. Expt. Sta. Ann. Rpt.* 1900-1901: 173-186. 1901.
69. FEED, E. B. Relation of green manures to the failure of certain seedlings. *Jour. Agr. Research* 5: 1161-1176. 1916.
70. FRED, E. B. The effect of certain organic substances on seed germination. *Soil Sci.* 6: 333-342. 1918.
71. FRED, E. B. The fixation of atmospheric nitrogen by inoculated soy beans. *Soil Sci.* 11: 469-472. 1921.
72. FRED, E. B. The influence of nitrifying bacteria on the growth of barley. *Soil Sci.* 18: 323-325. 1924.
73. FRED, E. B., and E. J. GRAUL. The effect of nitrogenous salts on nodule formation. *Jour. Amer. Soc. Agron.* 8: 316-328. 1916.
74. FRED, E. B., and E. J. GRAUL. The gain in nitrogen from growth of legumes on acid soils. *Wis. Agr. Expt. Sta. Research Bul.* 39. 1916.
75. FRED, E. B., and E. J. GRAUL. Some factors that influence nitrate formation in acid soils. *Soil Sci.* 1: 317-338. 1916.
76. FRSD, E. B., and E. B. HART. The comparative effect of phosphates and sulphates on soil bacteria. *Wis. Agr. Expt. Sta. Research Bul.* 35. 1915.
77. FULMER, H. L. The relation of green manures to nitrogen fixation. *Soil Sci.* 4: 1-17. 1917.
78. FULMER, H. L. Influence of carbonates of magnesium and calcium on bacteria of certain Wisconsin soils. *Jour. Agr. Research* 12: 463-504. 1918.
79. GAINEY, P. L. The effect of time and depth of cultivating a wheat seed bed upon bacterial activity in the soil. *Soil Sci.* 2: 193-204, 1916.
80. GAINEY, P. L., and L. F. METZLER. Some factors affecting nitrate nitrogen accumulation in the soil. *Jour. Agr. Research* 11: 43-64. 1917.
81. GARCIA, FABIAN. Peas as an orchard green manure and cover crop. *N. M. Agr. Expt. Sta. Bul.* 99. 1915.
82. GARNER, W. W., W. M. LUNN and D. E. BROWN. Effects of crops on the yields of succeeding crops in the rotation, with special reference to tobacco. *Jour. Agr. Research* 30: 1095-1152. 1925.
83. GERLACH and SEIDEL. Über die Kohlensauredüngung der Felder. *Mitt. Deut. Landw. Gesell.* 40: 919-922. 1925.
84. GIVEN, G. C, and G. J. KUHLMANN, JR. Velocity of nitrification in soils of the general fertilizer series. *Penn. Agr. Expt. Sta. Ann. Rpt.* 445-451. 1916.

85. GORTNER, R. A., and WM. M. SHAW. The organic matter of the soil, IV. Some data on humus-phosphoric acid. *Soil Sci.* 3: 99-111. 1917.
86. GOULD, HARRIS P. Peach growing. The Macmillan Co., New York. 1918.
87. GOWDA, R. NAGAN. Oxidation of ammonia and nitrites by microörganisms under different conditions. *Soil Sci.* 17: 57-64. 1924.
88. GRAY, L. C, and OTHERS. The utilization of our lands for crops, pasture and forests. *U. S. Dept. Agr. Yearbook, 1923:* 415-506. 1924.
89. GREAVES, J. E. The influence of salts on the bacterial activities of the soil. *Soil Sci.* 2: 443-480. 1916.
90. GREEN, W. W. Crop rotation and fertilizer experiments with suncured tobacco. *Va. Agr. Expt. Sta. Bul.* 196. 1912.
91. GREENWAY, JAMES. An account of the beneficial effects of *Cassia chamaecrista* in recruiting worn-out lands . . . botanical description of the plant. *Trans. Amer. Phil. Soc. Phila.* 3: 226-227. 1792.
92. GUNTHER and SEIDEL. Beitrag zur Kalkempfindlichkeit der Lupine. *Deut. Landw. Presse* 53: 221-222. 1926.
93. HALL, A. D. The value of different crops as green manures. *Jour. Brd. Agr.* (Gt. Britain.) 17: 969-974. 1911.
94. HALL, A. D. The book of the Rothamsted Experiments. 2nd Ed. Revised by E. J. Russell. John Murray, Albemarle St., W. London. 1917.
95. HALL, A. D., N. H. J. MILLER and C. T. GIMINGHAM. Nitrification in acid soils. *Proc. Roy. Soc. London Ser. B.* 80: 196-212. 1908.
96. HALL, THOMAS D. Nitrification in some South African soils, II. *Soil Sci.* 18: 219-235. 1924.
97. HARLAN, CALEB. Farming with green manures. 1st Ed. 1876. 7th Ed., Delore Pub. Co. Wilmington, Del., 1912.
98. HARLER, C. R. Tea in Japan. *Indian Tea Assn. Sci. Dept. Quar. Jour.* Pt. 1: 3-46. 1924
99. HARLER, C. R. Tea in Ceylon. *Indian Tea Assn. Sci. Dept. Quar. Jour.* Pt. 4: 193-226. 1924.
100. HARRISON, W. H., and P. A. SUBHAMANIA AIYER. The gases of swamp rice soils; their composition and relationship to the crop. *Memoirs Dept. Agr. India. Chem. Ser.* 3: 65-106. 1913.
101. HARRISON, W. H., and P. A. SUBRAMANIA AIYER. The gases of swamp rice soils; Pt. IV. The source of the gaseous soil nitrogen. *Memoirs Dept. Agr. India. Chem. Ser.* 5: 1-31. 1916.
102. HARTWELL, B. L. Effect of crops on each other. *R. I. Agr. Expt. Sta. 32nd Ann. Rpt.* 1920.
103. HARTWELL, B. L., and F. K. CRANDALL. The substitution of stable manure by fertilizers, green manures and peat. *R. I. Agr. Expt. Sta. Bul.* 188. 1922.
104. HARTWELL, B. L., and S. C. DAMON. The influence of crop plants on those which follow, I. *R. I. Agr. Expt. Sta. Bul.* 175. 1918.
105. HARTWELL, B. L., and F. R. PEMBER. The gain in nitrogen during a 5-year pot experiment with different legumes. *R. I. Agr. Expt. Sta. Bul.* 147. 1911.
106. HARTWELL, B. L., and F. R. PEMBER. The effect in pot cultures of green manures in different stages of growth and decomposition on the subsequent crops. *Jour. Amer. Soc. Agron.* 16: 750-752. 1924.
107. HARTWELL, B. L., F. R. PEMBER and G. E. MERKLE. The influence of crop plants on those which follow, II. *R. I. Agr. Expt. Sta. Bul.* 176. 1919.
108. HENRY, W. A., and F. B. MORRISON. Feeds and feeding. The Henry-MORRISON Co., Madison, Wis., 18th Ed. 1923.
109. HILGARD, E. W. Soils, their formation, properties, composition and relation to climate and plant growth in the humid and arid regions. The Macmillan Co., New York. 1919.
110. HILL, H. H. A comparison of methods for determining soil acidity and a study of the effects of green manures on soil acidity. *Va. Agr. Expt. Sta. Tech. Bul.* 19. 1919.
111. HILLS, T. L. Influence of nitrates on nitrogen assimilating bacteria. *Jour. Agr. Research* 12: 183-230. 1918.

112. HILTNER, L. Über neuere Ergebnisse und Probleme auf dem Gebiet der landwirtschaftlichen Bakteriologie. *Jahresber. Ver. Angew. Bot.* 5: 200-222. 1907.
113. HILTNER, L., and L. PETERS. Versuche über die Wirkung der Strohdüngung auf die Fruchtbarkeit des Bodens. *Arb. K. Biol. Anst. Land. U. Forstw.* 99: 8-125. 1907.
114. HINKLE, S. F. Fertility and crop production. Sandusky, Ohio. 1925.
115. Hiss, PHILIP HANSON and HANS ZINSSER. A text book of bacteriology. Appleton & Co., New York. 1914.
116. HOFFMAN, M. GRUNDUNGÜNGSWIRTSCHAFTEN. *Arb. Deut. Landw. Gesell.* 200. 1911.
117. HOFFMAN, M. Viehlose Wirtschaften. *Arb. Deut. Landw. Gesell.* 310. 1921.
118. HOLLAND, T. H. Some green manure and cover plants. *Dept. Agr. Ceylon Leaflet* 30. 1924.
119. HOLLAND, T. H. Tea manurial experiments at the experiment station, Peradiniya. *Trop. Agr. (Ceylon).* 65: 3-9. 1925.
120. HOLLAND, T. H. Green manures and cover plants. *Planter's Chron.* 21: 85-88. 1926.
121. HOLTZ, H. F., and H. P. SINGLETON. Comparative value of alfalfa and sweet clover on soils in the lower Yakima Valley. *Jour. Amer. Soc. Agron.* 17: 326-333. 1925.
122. HOPKINS, CYRIL G. Nitrogen bacteria and legumes. *Ill. Agr. Expt. Sta. Bul.* 94. 1904.
123. HOPKINS, CYBIL G. Soil fertility and permanent agriculture. Ginn & Co., Boston. 1910.
124. HOPKINS, CYRIL G., and J. P. AUMER. Potassium from the soil. *Ill. Agr. Expt. Sta. Bul.* 182. 1915.
125. HOWARD, ALBERT. Soil factors on disease resistance. *Ann. Appl. Biol.* 7: 373. 1921.
126. HOWARD, A., and G. F. C. HOWARD. Notes on drainage and green manuring. *Agr. Jour. India* 9: 197-204. 1914.
127. HOWARD, A., and G. F. C. HOWARD. The improvement of tobacco cultivation in Bihar. *Agr. Research Inst. Pusa Bul.* 50. 1915.
128. HOWARD, L. P. The reaction of the soil as influenced by the decomposition of green manure. *Soil Sci.* 9: 27-39. 1920.
129. HUGHES, H. D. Woods clover *(Dalea alopecuroides). Iowa State College, Farm Crops Department.* (Unnumbered circular.) 1925.
130. HUME, HAROLD. Citrus fruits and their culture. Orange Judd Co., New York. 1915.
131. HUTCHINSON, C. M., and S. MILLIGAN. Green manuring experiment 1912-1913. *Agr. Research Inst. Pusa Bul.* 40. 1914.
132. HUTCHINSON, H. B., and E. H. RICHARDS. Artificial farmyard manure. *Jour. Min. Agr. (Gt. Brit.)* 28: 398-411. 1921.
133. JENKINS, E. H. Timothy as a cover crop for tobacco land. *Conn. Agr. Expt. Sta. Bui.* 231: 354-356. 1921.
134. JENSEN, CHARLES A. Effect of decomposing organic matter on the solubility of certain inorganic constituents of the soil. *Jour. Agr. Research* 9: 253-268. 1917.
135. JOACHIM, A. W. R. A review of scientific investigations on green manuring in India. *Trop. Agr. (Ceylon)* 65: 325-331. 1925.
136. JODIDI, S. L. The chemical nature of the organic nitrogen in the soil. *Iowa Agr. Expt. Sta. Research Bul.* 3. 1911.
137. JODIDI, S. L. The chemistry of humus, with special reference to the relation of humus to the soil and to the plant. *Jour. Franklin Inst.* 176: 565—573. 1913.
138. JOHNSON, T. C. Green crops and fertilizers in place of manures. *Amer. Fertilizers* 57: 28-29. 1922.
139. JOHNSON, T. C. Effect of organic matter in maintaining soil fertility for truck crop production. *Proc. Amer. Soc. Hort. Sci.* 21: 277-281. 1924.

140. JONES, J. S., and D. E. BULLIS. A chemical study of legumes and other forage crops of Western Oregon. *Ore. Agr. Expt. Sta. Bul.* 197. 1923.
141. JOSHI, N. V. Rate of nitrification of different green manures and parts of green manures and the influence of crop residues on nitrification. *Agr. Jour. India.* 14: 395-413. 1919.
142. JOSHI, N. V. Comparative manurial value of the whole plant and the different parts of green manures. *Agr. Research Inst. Pusa Bul.* 141. 1922.
143. JOST, LUDWIG. Verlesungen über Pflanzenphysiologie. 2nd Ed. Jena. 1908.
144. KELLEY, W. P. Rice soils of Hawaii: their fertilization and management. *Hawaii Agr. Expt. Sta. Bul.* 31. 1914.
145. KELLNER, O., H. SAKANO, D. SATO and S. SHINJO. Researches on the action of lime as a manure, with special regard to paddy fields. *Imp. Univ. Col. Agr. Konada, Tokio, Japan Bul.* 9. 1891.
146. KELLNER, O., Y. KOSAI, Y. MORI and M. NAGAOKA. Manuring experiments with paddy rice. *Imp. Univ. Col. Agr. Konada, Tokio, Japan Bul.* 10. 1891.
147. KENNEDY, P. B., and B. A. MADSON. The mat bean, *Phaseolus aconitifolius. Calif. Agr. Expt. Sta. Bul.* 396. 1925.
148. KEUCHENIUS, A. A. M. N. Botanische kenmerken en cultuurwaarde als groenbemesters van een 60-tal nieuwe soorten van leguminosen. *Proefsta. Thee Meded.* 90: 44. 1924.
149. KHAN, MALIK ALI SULTAN. Green manuring with bhang on barani. *Punjab Dept. Agr. Rpt.* Pt. 2: 1-45. Year Ending June 30, 1924.
150. KING, F. H. Farmers of forty centuries or permanent agriculture in China, Korea and Japan. Mrs. F. H. King, Madison, Wis. 1911.
151. KING, F. H., and A. R. WHITSON. Development and distribution of nitrates in cultivated field soils. *Wis. Agr. Expt. Sta. 18th Ann. Rpt.* 210-231. 1901.
152. KING, F. H., and A. R. WHITSON. Development and distribution of nitrates and other soluble salts in cultivated soils. *Wis. Agr. Expt. Sta. Bul.* 85. 1901.
153. KINMAN, C. F. Cover crops for Porto Rico. *Porto Rico Agr. Expt. Sta. Bul.* 19. 1916.
154. KLING, M. Über die chemische Zusammensetzung einiger Unkräuter sowie deren Wert als Futter und Düngemittel. *Landw. Vers. Sta.* 85: 433-470. 1914.
155. KNAPP, S. A. Recent foreign explorations. *U. S. Dept. Agr. Bur. Plant Indus. Bul.* 35. 1903.
156. KNIGHT, J. B. Work of the Maujri Farm for the years 1915-1918. Maujri Agr. Sta. *Bombay Dept. Agr. Bul.* 90. 1918.
157. KOCH, ALFRED. Ergebnisse Zehnjahriger vergleichcnder Feldversuche über die Wirkung von Brache, Stalldünger und Klee. *Jour. für Landw.* 61: 245-281. 1913.
158. KOCH, L. The value of some green manure. *Trop. Agr.* 62: 351-356. 1924.
159. KOPELOFF, NICOLAS and D. A. COLEMAN. A review of investigations in soil Protozoa and soil sterilization. *Soil Sci.* 3: 197-269. 1917.
160. KRAUS, C. Untersuchungen über die Bewurzelung der Kulturpflanzen in physiologischer und kultureller Beziehung. *Forsch. Gebiete Agrik.-Phys.* 19:80-129. 1896.
161. KRAUSS, F. G. Leguminous crops for Hawaii. *Hawaii Agr. Expt. Sta. Bul.* 23. 1911.
162. KBAUSS, F. G. The pigeon pea *(Cajan indicum):* its culture and utilization in Hawaii. *Hawaii Agr. Expt. Sta. Bul.* 46. 1921.
163. KRAUSS, F. G. The pigeon pea. *Ext. Letter Univ. Hawaii* 224. 1926.
164. KRISTENSEN, R. K. Chemical studies of soil cultivated in various ways. *Tidsskr. Planteavl.* 26: 335-361. 1919. E. S. R. 42: 123. 1920.
165. KÜHN, JULIUS. Die wirthschaftliche bedeutung der Gründiingung. *Ztschr. Landw. Cent. Ver. Prov. Sachsen* 50: 3-13, 95-101, 117-128. 1893.
166. LANDER, P. E., B. H. WILDSON and M. MUKAND LAL. A study of the factors operative in the value of green manure. *Agr. Research Inst. Pusa Bul.* 149. 1923.
167. LECLAIR, C. A. Influence of growth of cowpeas upon some physicial, chemical and biological properties of soil. *Jour. Agr. Research* 5: 439-448. 1915.

168. LEMMERMANN, O. Untersuchungen über verschiedene Düngungsfragen. *Arb. Deut. Landw. Gesell.* 297: 198. 1919.
169. LEMMERMANN, O., and A. TAZENKO. Üntersuchungen über die Umsetzung des Stickstoffs verschiedener Gründüngungspflanzen im Boden. *Landw. Jahrb.* 38: Erganzungsband 5: 101-112. 1909.
170. LEMMERMANN, O., K. ASO, H. FISCHER and L. FRESENIUS. Untersuchungen über die Zersetzung der Kohlenstoffverbindungen verschiedener organischer Substanzen im Boden, speziell unter dem Einfluss von Kalk. *Landw. Jahrb.* 41:217-256. 1911.
171. LIPMAN, C. B., and L. J. H. TEAKLE. The fixation of nitrogen by azotobacter in a displaced solution and in soil residue therefrom. *Soil Sci.* 19: 99-103. 1922.
172. LIPMAN, JACOB G. Bacteria in relation to country life. The Macmillan Company, New York. 1908.
173. LIPMAN. JACOB G. Tests of commercial cultures for soil inoculation. *N. J. Agr. Expt. Sta. Bul.* 227. 1910.
174. LIPMAN, JACOB G., and A. W. BLAIR. Cylinder experiments relative to the utilization and accumulation of nitrogen. *N. J. Agr. Expt. Sta. Bul.* 289. 1916.
175. LIPMAN, JACOB G., and A. W. BLAIR. Influence of lime upon the yield of dry matter and nitrogen content of alfalfa. *N. J. Agr. Expt. Sta. Bul.* 316. 1917.
176. LIPMAN, JACOB G., and A. W. BLAIR. A comparative study of the value of nitrate of soda, leguminous green manures and stable manure in cylinder experiments 1907-1909. *Jour. Agr. Sci.* 11: 323-336. 1921.
177. LIPMAN, JACOB G., and A. W. BLAIR. Nitrogen losses under intensive cropping. *Soil Sci.* 12: 1-19. 1921.
178. LIPMAN, JACOB G., A. W. BLAIR, IRVING L. OWEN and H. C. MCLEAN. Miscellaneous vegetation studies. *N. J. Agr. Expt. Sta. Bul.* 250. 1912.
179. LIPMAN, JACOB G., A. W. BLAIR, IRVING L. OWEN and H. C. MCLEAN. The influence of bacteria supplied in manure on the decomposition of green manure. (Legume and non-legume.) *N. J. Agr. Expt. Sta. Ann. Rpt.* 248-260. 1912.
180. LÖHNIS, F. Handbuch der landwirtschaftlichen Bakteriologie. G. Borntraeger, Berlin. 1910.
181. LÖHNIS, F. Bacterial nitrogen fixation. *Jour. Amer. Soc. Agron.* 17: 445-450 1925.
182. LÖHNIS, F. Nitrogen availability of green manures. *Soil Sci.* 22: 253-290 1926.
183. LONSDALE, T. W. Green manuring. *Jour. Brd. Agr. New Zeal.* 8: 475. 1914.
184. LUMIERE, AUGUSTE. Action nocive des feuilles mortes sur le germination. *Compt. Rend. Acad. Sci. (Paris)* 172: 232-234. 1921.
185. LYON, T. L., and J. A. BIZZELL. Experiments concerning the top-dressing of timothy and alfalfa. *N. Y. (Cornell) Agr. Expt. Sta. Bul.* 339: 119-143 1913.
186. LYON, T. L., and J. A. BIZZELL. Lysimeter experiments. *N. Y. (Cornell). Agr. Expt. Sta. Memoirs* 12. 1918.
187. LYON, T. L., and H. O. BUCKMAN. The nature and properties of soils. The Macmillan Co., New York. 1922.
188. MCBETH, I. G. Studies on the decomposition of cellulose in soils. *Soil Sci.* 1: 457-487. 1916.
189. MCCALL, T. M. Potato culture and fertility practices in the Red River Valley. *Potato News Bul.* 2: 488-491. 1925.
190. MCCOOL, M. M. The nitrogen content of alfalfa. *Mich. Quar. Bul.* 8:122-123. 1926.
191. MCCUE, C. A. Cover crops in peach orchards. *Del. Agr. Expt. Sta. Bul.* 120 1918.
192. MCKEE, ROLAND. Orchard green manuring crops in California. *U. S. Dept. Agr. Bur. Plant Indust. Bul.* 190. 1910.
193. MCLEAN, HAERY C, and GUY W. WILSON. Ammonification studies with soil fungi. *N.J. Agr. Expt. Sta. Bul.* 270. 1914.
194. MACTAGGERT, ALEXANDER. The influence of certain fertilizer salts on the growth and nitrogen content of some legumes. *Soil Sci.* 11: 435-454. 1921.

195. MAERCKEB, MAX and H. STEPFECK. Über die Stickstoffwirkung verschiedener Gründüngungspflanzen. *Jahrb. Agr. Chem. Ver. Sta.* 2: 142-145. 1897.
196. MANN, HAROLD M., and C. M. HUTCHINSON. Green manuring in tea culture in India. *Indian Tea Assoc. Bul.* 2. 1906.
197. MARTIN, THOS. LYSON. Decomposition of green manures at different stages of growth. *N. Y. (Cornell) Agr. Expt. Sta. Bul.* 406: 139-169. 1921.
198. MASON, J. R. Sweet clover in eastern Colorado—Repeated proofs it increases beet yields. *Through the Leaves,* 14: 99-102. 1926.
199. MAYNARD, L. A. The decomposition of sweet clover *(Melilotus alba)* as a green manure under greenhouse conditions. *N.Y. (Cornell) Agr. Expt. Sta. Bul.* 394. 1917.
200. MEHER, L. Einige Erfahrungen mit Gründüngung im ostlichen Deutschland. *Mitt. Deut. Landw. Gesell.* 37: 422-424. 1922.
202. MERTZ, W. M. Green manure crops in Southern California. *Calif. Agr. Expt. Sta. Bul.* 292. 1918.
201. MERKLE, FEED C. The decomposition of organic material in soils. *Jour. Amer. Soc. Agron.* 10: 281-302. 1918.
203. MIELCK, OTPRIED. Die Wirkungen der Gründiingung. *Fuhling's Landw. Ztg.* 62: 585-612. 1913.
204. MILLER, H. A. A simple way to increase crop yields. *U. S. Dept. Agr. Farmers' Bul.* 924. 1918.
205. MILLER, M. F. Effect of the addition of organic matter to the soil upon the development of soil acidity. *Mo. Agr. Expt. Sta. Bul.* 147: 50-51. 1917.
206. MILLSPAUGH, C. F. Your weeds and your neighbors. *West Va. Agr. Expt. Sta. Bul.* 19. 1891.
207. MOLEGODE, W. Green manuring of paddy fields in the Kandy District. *Trop. Agr. (Ceylon)* 51: 349. 1918.
208. MOLEGODE, W. Green manuring and paddy cultivation. *Trop. Agr. (Ceylon)* 56: 3-4. 1921.
209. MOOERS, C. A. Effects of liming and green manuring on crop yields and on soil supplies of nitrogen and humus. *Term. Agr. Expt. Sta. Bul.* 135. 1926.
210. MOOERS, C. A., H. H. HAMPTON and W. K. HUNTER. Pt. 3. The effect of liming and of green manuring on the soil content of nitrogen and humus. *Tenn. Agr. Expt. Sta. Bul.* 96. 1912.
211. MORRIS, O. M. Thirtieth Annual Report, *Wash. Agr. Expt. Sta. Bul.* 158: 27. 1920.
212. MORTIMER, JOHN. The whole art of husbandry or the way of managing and improving of land. London. 1912.
213. MOSIER, J. G. The physical improvement of soils. *Ill. Agr. Expt. Sta. Circ.* 82. 3d Ed. 1912.
214. MOSIER, J. G., and A. J. GUSTAFSON. Soil physics and management. J. B. Lippincott & Co., Philadelphia and London. 1917.
215. MUSGRAVE, GEO. W. Winter cover and green-manure crop. Report of the the Dept. of Agron. *N. J. Agr. Expt. Sta. Ann. Rpt. Year Ending June 30, 1914.* 1915.
216. NEIDIG, RAY E., G. R. MCDOLE and H. P. MAGNUSON. Effect of sulphur, calcium and phosphorus on the yield and composition of alfalfa on six types of Idaho soils. *Soil Sci.* 16: 127-136. 1923.
217. NELLER, J. R. The influence of sulfur and gypsum upon the composition and yield of legumes. *Wash. Agr. Expt. Sta. Bul.* 190. 1925.
218. NIKLAS, H., K. SCHARRER and A. STROBEL. Beiträge zur Frage der Kohlensauredtingung. *Landw. Jahrb.* 60: 349-377. 1924.
219. NOBBE, F., and L. RICHTER. Über den Einfluss des im Kulturboden vorhandenen assimilierbaren Stickstoffs auf die Aktion der Knollchenbakterien. *Landw. Vers. Sta.* 59: 167-174. 1903.
220. NOLL, C. F. Effect of fertilizers on soil structure as indicated by the draft of a plow. *Venn. Agr. Expt. Sta. Ann. Rpt.* 36-46. 1913-1914. Separate 3. 1916.
221. NOLTE, O. Gründüngung in Theorie und Praxis. *Flugschr. Deut. Landw. Gesell.* 23. 1923.

222. NOVIKOFF, M. Die Bodensprotozoen und ihre Bedeutung für die Bodenkultur. Akten der von Portheim-Stiftung. Heidelberg. 1923. *Internat. Rev. Sci. and Pract. Agr. (Rome).* N. S. 3(1): 151. 1925.
223. ONODERA, ISENOSUKE. Über die Gase welche im Reisfelde bei der Zersetzung von Genge *(Astragalus sinicus)* entstehen. *Ber. Ohara Inst. Landw. Forsch.* I. 557-578. 1920.
224. PADDOCK, WENDELL and ORVILLE B. WHIPPLE. Fruit-growing in arid regions. The Macmillan Co., New York. 1914.
225. PAGE, H. J. The part played by organic matter in the soil system. *Trans. Faraday Soc.* 17: 272-286. 1921.
226. PAGE, H. J. Green manuring. *Jour. Min. Agr.* (Gt. Britain). 29:104-112; 240-248. 1922.
227. PAGE, H. J. Experiments on green manuring for light soils. *Jour. Roy. Hort. Soc. (London)* 47: 175-188. 1922.
228. PANGANIBAN, ELIAS H. Temperature as a factor in nitrogen changes in the soil. *Jour. Amer. Soc. Agron.* 17: 1-31. 1925.
229. PARKINSON, RICHARD. The experienced farmer. Charles Cist, Philadelphia. 1799.
230. PENNY, CHARLES L. Cover crops as green manure. *Del. Agr. Expt. Sta. Bul.* 60. 1903.
231. PENNY, CHARLES L. The growth of crimson clover *(T. incarnatum). Del. Agr. Expt. Sta. Bul.* 67. 1905.
232. PIETERS, ADRIAN J. Green manuring: A review of the American Experiment Station Literature. *Jour. Amer. Soc. Agron.* 9: 62-82, 109-126, 162-190. 1917.
233. POTTER, R. S. and R. S. SNYDER. Carbon dioxide production in soils and carbon and nitrogen changes in soils variously treated. *Iowa Agr. Expt. Sta. Research Bul.* 39. 1916.
234. POTTER, R. S., and R. S. SNYDER. Decomposition of green and stable manures in soil. *Jour. Agr. Research* 11: 677-698. 1917.
235. PRICE, O. B. Mineral content of alfalfa increased by proper fertilization. *Mich. Agr. Expt. Sta. Quar. Bul.* 5: 158-159. 1923.
236. RAHN, O. Die schädliche Wirkung der Strohdüngung und deren Verhütung. *Ztschr. Tech. Biol. 7:* 172-186. 1919. Abst.: E. S. R. 46: 818. 1922.
237. RAMACHANDRO RAO, D. G. Green manuring experiments on the Marthur Farm. *Trop. Agr. (Ceylon).* 61: 248. 1923.
238. REINHOLD, C. G. The farmers' promotion book. Pittsburgh. 1856.
239. RIPPEL, AUGUST. Stickstoffhaushalt im Ackerboden mit besonderer Berücksichtigung der Brache. *Mitt. Deut. Landw. Gesell.* 40; 26-28. 1925.
240. ROSENFELD, ARTHUR H. A demonstration of the value of crop rotation in practical cane culture. *Sugar (Chicago)* 18: 463-464. 1916.
241. RUSSELL, EDWARD J. The nature and amount of the fluctuations in nitrate content of arable soils. *Jour. Agr. Sci.* 6: 18-57. 1914.
242. RUSSELL, EDWARD J. Soil conditions and plant growth. Longmans, Green & Co., London. 1915.
243. RUSSELL, EDWARD J., and A. APPLEYARD. The influence of soil conditions on the decomposition of organic matter in the soil. *Jour. Agr. Sci.* 8: 385-417. 1917.
244. RUSSELL, EDWARD J., and H. B. HUTCHINSON. The effect of partial sterilization of soil on the production of plant food. *Jour. Agr. Sci.* 3: 111-114, 1909: 5:152-221. 1913.
245. RUSSELL, J. C, E. G. JONES and G. M. BAHRT. The temperature and moisture factors in nitrate production. *Soil Sci.* 19: 381-398. 1925.
246. SCHERFFIUS, W. H. Green manuring. *Trop. Agr.* 53: 315-318. 1919.
247. SCHNEIDEWIND, W., D. MEYER, F. MUNTER, J. GRAFF and W. GROBLER. Die Wirkung der Gründüngung. Siebenter Berichte über die Versuchswirtschaft-Lauchstadt. *Landw. Jahrb.* 39. Erganzungsband 3: 80-91. 1910.
248. SCHNEIDEWIND, W., D. MEYER, B. HEINZE, F. MÜNTER and J. GRAFF. Die Wirkung des Gründüngungstickstoff. Arbeiten der Agri. Chem. Versuchstation Halle. *Landw. Jahrb.* 39. Erganzungsband 3: 231-233. 1910.

249. SCHREINER, OSWALD. Toxic organic soil constituents and the influence of oxidation. *Jour. Amer. Soc. Agron.* 15: 270-276. 1923.
250. SCHREINER, OSWALD. Changes in character, condition and amount of soil organic matter. *Jour. Amer. Soc. Agron.* 18: 115-126. 1926.
251. SCHHEINER, OSWALD and J. J. SKINNER. Nitrogenous soil constituents and their bearing on soil fertility. *U. S. Dept. Agr. Bur. Soils Bul.* 87. 1912.
252. SCHULTZ-LUPITZ. Zwischenfruchtbau auf leichtem Boden. *Arb. Deut. Landw. Gesell. 7.* 3d Auflage. 1897.
253. SCHULZE, B. Wurzelatlas. Paul Parey, Berlin. 1914.
254. SCOTT, HERSCHEL. The influence of wheat, straw on the accumulation of nitrate in the soil. *Jour. Amer. Soc. Agron.* 13: 233-258. 1921.
255. SEELHORST, C. VON. Der Verbleib des Gründüngungstickstoffs im Sandboden auf Grund von Vegetationsversuchen. *Arb. Deut. Landw. Gesell.* 241. 1913.
256. SEIDEN, RUDOLF. Vergleichende Untersuchungen über den Einfluss verschiedener Äusserer Faktoren insbesondere auf den Aschengehalt in den Pflanzen. *Landw. Vers. Sta.* 104: 1-50. 1926.
257. SEWELL, M. C. Effect of *Andropogon sorghum* on succeeding crops of *Triticum sativum vulgare. Bot. Gaz.* 75: 1-26. 1923.
258. SHERARD, J. L. The Hodges method of soil building. Oulla Printing and Binding Co., Anderson, S. C. 1917.
259. SIDENIUS, I. E. Eenige practische wenken betreffende de toepassing van *Mimosa invisa* als grondbedekker bij de Delische Tabakscultuur. *Meded. Deli Proefsta. Medan.* Tweede Serie. 36. 1924.
260. SIEVERS, F. J. Soil nitrate studies. *Thirty-first Ann. Rpt. Wash. Agr. Expt. Sta. Bui.* 167: 44-47.' 1921.
261. SIEVERS, F. J., and H. F. HOLTZ. The silt loam soils of eastern Washington and their management. *Wash. Agr. Expt. Sta. Bul.* 166. 1922.
262. SIEVERS, F. J. and H. F. HOLTZ. The maintenance of organic matter in eastern Washington soils. *Thirty-fourth Ann. Rpt. Wash. Agr. Expt. Sta. Bul.* 187: 74-75. 1924.
263. SIEVERS, F. J., and H. F. HOLTZ. The significance of nitrogen in soil organic matter relationships. *Wash. Agr. Expt. Sta. Bul.* 206. 1926.
264. SKINNER, J. J. Illustration of the effect of previous vegetation on a following crop: Cabbage after Sesame. *Plant World* 16: 342-346. 1913.
265. SKINNER, J. J., and J. B. DEMAREE. Relation of soil conditions and orchard management to the rosette of pecan trees. *U. S. Dept. Agr. Bul.* 1378. 1926.
266. SMITH, C. D., and F. W. ROBISON. Influence of nodules on the roots upon the composition of soybeans and cowpeas. *Mich. Agr. Expt. Sta. Bul.* 224: 128-137. 1905.
267. SNIDER, H. J., and M. A. HEIN. The nitrogen and dry matter content of sweet clover tops and roots at various stages of growth. *Jour. Amer. Soc. Agron.* 18: 273-280. 1926.
268. SNYDER, HARRY. Humus in its relation to soil fertility. *U. S. Dept. Agr. Yearbook* 1895: 131-142. 1896.
269. SNYDER, HARRY, Characteristic features of Minnesota soils and conservation of fertility. *Minn. Agr. Expt. Sta. Bul.* 65. 1899.
270. SNYDER, HARRY. Forage crops of high, medium and low protein content. *Minn. Agr. Expt. Sta. Bul.* 101. 1907.
271. SNYDER, HARRY. Soils and fertilizers. The Macmillan Co., New York. 1908.
272. SPRING, F. G. Annual Report of the Agriculturist (Rubber) for the year 1925, *Malayan Agr. Jour.* 14. 175-178. 1926.
273. STARKEY, ROBERT L. Some observations on the decomposition of organic matter in soils. *Soil Sci.* 18. 293-314. 1924.
274. STEPHENSON, R. E. The effect of organic matter on soil reaction. *Soil Sci.* 6. 413-439. 1918.
275. STEWART, H. R. Annual Report of the Lyallpur Agricultural Station for the Year ending June 30, 1924. *Punjab Dept. Agr. Rpt.* 2: 102-166. 1924.
276. STEWART, ROBERT. The Illinois system of permanent soil fertility as developed by Cyril G. Hopkins. *Ill. Agr. Expt. Sta. Circ.* 245. 1920.

277. STOKES, W. E. The past season's results with Crotalaria as a cover crop and some plans for future work. *Proc. Fla. State Hort. Soc.* 1925. 10-13. 1925.
278. STORMER, K. Versuche über die Beeinflussung der Wirkung des Gründüngungs-Stickstoffs durch Zugabe von Stroh. *Fuhlings Landw. Ztg,* 60: 185-198. 1911.
279. STÜTZER, A., and L. SEIDLER. Der Gehalt einger Ackerunkräuter an wichtigen Pflanzennahrstoffen. *Fuhlings Landw. Ztg.* 57: 429-430. 1908.
280. SWANSON, C. O. The effect of prolonged growing of alfalfa on the nitrogen content of the soil. *Jour. Amer. Soc. Agron.* 9: 305-314. 1917.
281. TAGGART, W. G. Melilotus indica on fall plant cane. *La. Agr. Expt. Sta. Bul.* 189. 1923.
282. TEMPLE, J. C. The influence of stall manure upon the bacterial flora of the soil. *Ga. Agr. Expt. Sta. Bul.* 95. 1911.
283. THATCHER, R. W. The nitrogen and humus problem in dry farming. *Wash. Agr. Expt. Sta. Bul.* 105. 1912.
284. THEOPHRASTUS. Enquiry into plants and minor works on odours and weather signs with an English translation by Sir Arthur Hort, bart., W. Heinemann, London: G. P. Putnam's Sons, New York. 1916.
285. THOMAS, R., and J. CHELVARANGA RAJU. Reports of field crops work at the Palur Agricultural Station. *Madras Dept. Agr. Palur Agr. Sta. Rpt.* 1914-1915; 2-15; 1915-1916: 4-25; 1916-1917: 26. 1918.
286. THOMSPON, ALICE R. Chemical studies of the efficiency of legumes as green manures in Hawaii. *Hawaii Agr. Expt. Sta. Bul.* 43. 1917.
287. THORNBER, H. Cover crops, tillage and commercial fertilizers. *Better fruit,* 15 (2): 5,20-22. 1920.
288. THORNBER, H. The relative value of cover crops. *Better Fruit,* 16 (2). 9. 1921.
289. THORNBER, H. Effects of cover crops in the orchard. *Better Fruit,* 17 (1). 11-12. 1922.
290. THORNE, et al. The maintenance of soil fertility. *Ohio Agr. Expt. Sta. Bul.* 336: 577-646. 1919.
291. TRUE, RODNEY H., OTIS F. BLACK and JAMES W. KELLY. Ash absorption by spinach from concentrated soil solutions. *Jour. Agr. Research* 16. 15-25. 1919.
292. TRUOG, E. Factors influencing the availability of rock phosphate. *Wis. Agr. Expt. Sta. Research Bul.* 20. 1912.
293. ULLMANN. Raps und Senf als Gründüngung. *Deut. Landw. Presse* 21. 140-141. 1894.
294. ULRICH, R. Untersuchungen über die Wasserkapazitat der Boden. *Forsch. Gebiete Agrik. Phys.* 19. 37-56. 1896.
295. VAILE, ROLAND S. A survey of orchard practices in the citrus industry of Southern California. *Calif. Agr. Expt. Sta. Bul.* 374. 1924.
296. VAN DER MUELEN, G. F. De Bodembedekking in onze rubbertuinen. *Arch. Rubbercult. Nederland. Indie* 8. 191-197. 1924.
297. VAN HALL, C. J. J. Mimosa invisa. *Teysmannia* 5: 193-198. 1920.
298. VAN HELTEN, W. M. De resultaten verkregen in den cultuurtuin met verschillende groenbemesters. *Meded. Cultuur.* 1 and 2. 1913.
299. VAN HELTEN, W. M. Practische ervaringen met verschillende soorten groenbemesters. *Meded. Alg. Proefsta. Landb.* 16. 1924.
300. VABRO, MARCTJS TERENTIUS. Rerum Rusticarum. In Roman Farm Management by a Virginia Farmer, F. H. (Fairfax Harrison). The Macmillan Co., New York. 1913.
301. VIBRANS. Düngung mit Luftstickstoff sammelnden Pflanzen. *Deut. Landw. Presse* 20: 120-121. 1893.
302. VILJOEN, J. A., and E. B. FRED. The effect of different kinds of wood and of wood pulp cellulose on plant growth. *Soil Sci.* 17: 199-208. 1924.
303. VOELCKER, A. The Woburn Experimental Farm and its work, 1876-1921. *Jour. Roy. Agr. Soc. England* 84: 110-166. 1923.
304. VOORHEES, EDWARD B., and JACOB G. LIPMAN. A review of investigations in soil bacteriology. *U. S. Dept. Agr. Expt. Stas. Bui.* 194. 1907.

305. WAGNER, PAUL. Die Stickstoffdündung der Landwirtschftlichen Kulturpflanzen. Paul Parey, Berlin. 1892.
306. WAGNER, PAUL. Einige Zeit und Streitfragen aus dem Gebiet der Düngunglehre. *Deut. Landw. Presse* 20: 799-800. 1893.
307. WAGNER, PAUL. Gründüngung oder Stallmistdüngung. *Braunschweig. Landw. Ztg.* 62: 85-86, 89-90, 93-99. 1894.
308. WAKSMAN, SELMAN A. Studies on soil protozoa. *Soil Sci.* 1: 135-152. 1916.
309. WAKSMAN, SELMAN A. Bacterial numbers in soils at different depths and in different seasons of the year. *Soil Sci.* 1*:* 363-403. 1916.
310. WAKSMAN, SELMAN A. Soil fungi and their activities. *Soil. Sci.* 2: 103—155. 1916.
311. WAKSMAN, SELMAN A. Protozoa as affecting bacterial activities in the soil. *Soil Sci.* 2: 363-376. 1916.
312. WAKSMAN, SELMAN A. Is there any fungus flora of the soil? *Soil Sci.* 3: 565-589. 1917.
313. WAKSMAN, SELMAN A. The importance of mold action in soil. *Soil Sci.* 6: 137-154. 1918.
314. WAKSMAN, SELMAN A. Microbiological analysis of soil as an index to soil fertility: VI, nitrification. *Soil Sci.* 16: 55-67. 1923.
315. WAKSMAN, SELMAN A. Soil microbiology in 1924. An attempt at an analysis and a synthesis. *Soil Sci.* 19: 201-246. 1924.
316. WAKSMAN, SELMAN A. The origin and nature of the soil organic matter or soil "Humus": I, Introductory and Historical; II, Method of determining humus in the soil; III, The nature of the substances contributing to the formation of humus. *Soil Sci.* 22: 123-162; 221-232; 323-333. 1926.
317. WAKSMAN, SELMAN A., and ROLAND E. CURTIS. The actinomyces of the soil. *Soil Sci.* 1: 99-134. 1916.
318. WAKSMAN, SELMAN A., and O. HEUKELEKIAN. Microbiological analysis of soil as an index of soil fertility. VIII, Decomposition of cellulose. *Soil Sci.* 17: 275-291. 1924.
319. WAKSMAN, SELMAN A., and ROBERT L. STARKEY. Partial sterilization of soil, microbiological activities and soil fertility, I. *Soil Sci.* 16: 137-156; II, 16: 247-268. 1923.
320. WAKSMAN, SELMAN A., and ROBERT L. STARKEY. Influence of organic matter upon the development of fungi, actinomycetes and bacteria in the soil. *Soil Sci.* 17: 373-378. 1924.
321. WARINGTON, ROBERT. Six lectures on the investigations at Rothamsted Experimental Station. *U. S. Dept. Agr. Expt. Stas. Bul.* 8: 7-112. 1892.
322. WEITZ, B. O. An analysis of crop yield statistics with reference to soil deterioration. *Jour. Amer. Soc. Agron.* 18: 90-106. 1926.
323. WENHOLZ, H. Soil fertility. Its maintenance and improvement by means of rotation, cover and green-manure crops. *Agr. Gaz. N. S. Wales* 37: 27-36; 229-236; 374-376. 1926.
324. WENHOLZ, H., and H. BROADFOOT. Orchard green manuring or cover cropping. *Agr. Gaz. N. S. Wales* 37: 377-380. 1926.
325. WERNER, H. Handbuch des Futterbaus. Paul Parey, Berlin. 1907.
326. WHITE, J. W. Concerning the growth and composition of clover and sorrel *(Rumex acetosella)* as influenced by varied amounts of limestone. *Penn. Agr. Expt. Sta. Ann. Rpt.* 1913-1914; 46-64. 1914. Also Separate 4. 1916.
327. WHITE, J. W. Nitrification in relation to the reaction of the soil. *Penn. Agr. Expt. Sta. Ann. Rpt.* 1913-1914; 70-80. 1915.
328. WHITE, J. W. Soil acidity: The relation of green manuring to its development. *Penn. Agr. Expt. Sta. Ann. Rpt.* 1914-1915; 60-86. 1916.
329. WHITE, J. W. Soil acidity as influenced by green manures. *Penn Agr. Expt. Sta. Ann. Rpt.* 60-68. 1915.
330. WHITE, J. W. Soil acidity as influenced by green manures. *Jour. Agr. Research* 13: 171-197. 1918.
331. WHITE, J. W., and F. J. HOLBEN. Residual effects of forty years continuous manurial treatment, I. Effect of lime on decomposition of soil organic matter. *Soil Sci.* 18: 201-214. 1924.

332. WHITE, J. W. and F. J. HOLBEN. Residual effects of forty years continuous manurial treatment, II. Effect of caustic lime on soil treated with barnyard manure. *Soil Sci.* 20: 313-327. 1925.
333. WHITE, THOMAS H. Tests of the value of stable manure, commercial fertilizer and crimson clover for vegetable crops. *Md. Agr. Expt. Sta. Bul.* 199, 1916.
334. WHITING, A. L., and E. B. FRED. Inoculated seed increases yield and quality of legumes. *Wis. Agr. Col. Ext. Circ.* 194. 1926.
335. WHITING, ALBERT L., and THOMAS E. RICHMOND. Sweet clover for nitrate production. *Ill. Agr. Expt. Sta. Bul.* 233. 1921.
336. WHITING, ALBERT L., and THOMAS E. RICHMOND. Sweet clover in relation to the accumulation, loss and conservation of nitrates in soil. *Soil Sci.* 22: 1-19. 1926.
337. WHITING, ALBERT L., and THOMAS E. RICHMOND. The composition of white sweet clover as related to soil enrichment. *Soil. Sci.* 22: 83-95. 1926.
338. WHITING, ALBERT L., and WARREN T. SHOONOVER. The comparative rate of decomposition of green and cured clover tops in soil. *Soil Sci.* 9: 137-149. 1920.
339. WHITSON, A. R., C. W. STODDART and A. F. MCLEOD. The nitrogen content of soils as affected by methods of farming. *Wis. Agr. Expt. Sta. 23d. Ann. Rpt.* 160-170. 1906.
340. WILKINS, F. S. Hubam clover. *Iowa Agr. Expt. Sta. Circ.* 76. 1922.
341. WILLARD, C. J. When should sweet clover be plowed down. *Ohio Agr. Expt. Sta. Mo. Bul.* 10: 42-44. 1925.
342. WILLARD, C. J., and L. E. THATCHER. Experiments with Hubam clover. *Ohio Agr. Expt. Sta. Mo. Bul.* 7: 3-18. 1922.
343. WILLIAMS, C. G. The testimony of the field experiments of the country. *Jour. Amer. Soc. Agron.* 18: 106-114. 1926.
344. WILSON, J. K. Physiological studies of Bacillus radicicola of soybeans *(Soja max* Piper) and of factors influencing nodule formation. *N. Y. (Cornell) Agr. Expt. Sta. Bul.* 386. 1917.
345. WINOGRADSKY, S. The direct method in the microbiological study of soil. *Agr. Jour. India* 21: 134-139, 224-232. 1926.
346. WOLFINGER, JOHN F. Green manuring and manures. *Rept. U. S. Commissioner Agr. for the year 1864.* 299-328. 1865.
347. WOLLNY, EWALD. Der Einfiuss der Pflanzendecke und Beschattung auf die Physikalische Eigenschaften und die Fruchtbarkeit des Bodens. München, 1877.
348. WOLLNY, EWALD. Die Zersetzung der organischen Stoffe und die Humus-bildung mit Rücksicht auf die Bodencultur. Heidelberg. 1897.
349. WRIGHT, H. Experiments with green manures. *Circs, and Agr. Jour. Roy. Bot. Gards. (Ceylon).* 3: 137-154. 1905.
350. WRIGHT, R. CLAUDE. The influence of certain organic materials upon the transformation of soil nitrogen. *Jour Amer. Soc. Agron.* 7: 193-208. 1915.
351. WRIGHT, R. CLAUDE. Nitrogen economy in the soil as influenced by various crops grown under control conditions. *Soil Sci.* 10: 249-289. 1920.
352. YOUNG, FLOYD D. A further study of the relation between cover crops and orchard temperatures. *U. S. Dept. Agr. Weather Bur. Mo. Rev.* 53: 387-391 1925.