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U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1250

GREEN MANURING



GREEN MANURING means turning under suitable crops to enrich the soil. Such crops may be turned under green or when ripe.

Green manuring adds organic matter and, directly or indirectly, nitrogen to the soil.

Leguminous crops are most desirable for green manuring, since they add to the soil nitrogen gathered from the air in addition to the organic matter which they carry.

Besides the nitrogen in the legumes turned under, an additional supply of nitrogen is fixed in the soil by the action of bacteria, using the carbon in the organic matter as a source of energy.

Turning under an entire crop is advised only when the soil is poor and for the purpose of starting a rotation.

Turning under catch crops or winter-grown green crops is an economical and successful method of supplying nitrogen.

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief
Washington, D. C.
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GREEN MANURING.

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DEFINITION OF "GREEN MANURING."

"GREEN MANURING" means the turning under of green plants for the enrichment of the soil (see title-page). Taken broadly, this would mean the turning under of weeds or the aftermath of a grass or clover crop, as well as a crop especially grown for turning under. Commonly, however, the term is used in a narrower sense and is applied to the turning under of a green crop grown especially for the purpose; or if not grown especially, at least used in that way rather than put to some other possible use, as when the second crop of clover is turned under instead of being cut for hay or for seed. With perhaps minor modification, the same processes are involved and the same results are attained whether the plant material is turned under dry or green.

Cover crops frequently serve also as green-manure crops. However, when a cowpea cover crop is allowed to remain until spring and the dead vines are then worked into the soil, this operation can scarcely be spoken of as green manuring, but is more nearly like turning under crop residues.

"Green manuring," therefore, as used in this bulletin means the turning under of any crop, while green or soon after ripening, for

the purpose of soil improvement. While the turning under of crop residues serves to incorporate organic matter with the soil in the same way that green manuring does, economically the practice is very different. In green manuring, crops are turned under that might have been used for other purposes, while crop residues are commonly waste materials.

Green manuring is one of the oldest methods used to maintain or to increase the productivity of the soil. Green-manure crops were employed by the ancients, the Romans using lupines, which were sown in September and turned under in May for the benefit of the following crop. In Germany the use of lupines began in the middle of the nineteenth century and has proved an important factor in reclaiming the sandy lands of parts of Prussia.

In England both legumes and various crucifers are commonly used; in India and Japan the farmers gather green plants of many kinds, sometimes even cutting twigs from the trees and carrying this material to their rice fields; in China green plant material is usually composted and then used, but it is also sometimes turned under in place.

In the United States the use of special green-manure crops is much more general in the South than in the North. In the semiarid regions under dry farming green manures are not used, for reasons that will be made clear later, but under irrigation green manures play an important part in orchard culture in several Western States.

EFFECTS OF GREEN MANURING.

When a green-manure crop is turned under, the various fertilizing elements that have gone into the making of the crop are returned to the soil, and a quantity of organic matter not before in the soil is added. This organic matter serves as food for microorganisms and also improves the physical condition of the soil.

PHYSICAL EFFECTS.

Organic matter affects both the texture and the moisture-holding capacity of soils. Heavy clays are lightened and made more porous and sandy soils are enabled to hold moisture better. For the best growth of the roots of most crop plants both air and moisture are needed. When a stiff soil dries and becomes hard the air is excluded and the roots are likely to suffer not only from lack of moisture but from lack of air.

Clay soil containing organic matter is more friable than similar soil without organic matter. Where soil from which the organic matter had been extracted was allowed to freeze and thaw it remained compact and did not crumble. When the organic matter

previously dissolved out of this soil was returned to it the soil crumbled after freezing, the same as the original soil.

Some crop plants, as alsike clover and rice, thrive in a water-soaked soil, and wheat has been successfully matured in sealed pots from which air was excluded. In general, however, experience has amply shown that most crop plants do better when the soil in which they grow is in good tilth. This condition of good tilth is facilitated by organic matter.

Not only do the higher plants grow better in a soil rich in organic matter, but the activities of the soil bacteria are largely dependent on the supply of decaying vegetable matter. These bacteria need food and air. Their food is the dead vegetable matter, which they break down and thus make available to the higher plants. Most beneficial bacteria use air, and this they find more abundantly in a soil supplied with organic matter than in stiff clays poor in organic matter. In sandy soils there is air enough, but the addition of humus helps to hold moisture and so benefits the bacteria as well as the higher plants.

It has been shown that while 100 pounds of sand can hold only 25 pounds of water and 100 pounds of clay 50 pounds, the same weight of humus or decaying organic matter will hold 190 pounds. A good physical condition of the soil, therefore, largely depends on the organic matter in the soil.

CHEMICAL EFFECTS.

The soil in which plants grow must not be thought of as a layer of dead matter in which the 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.

Besides the elements that plants need, there are many other substances in soils, and changes are constantly going on which make the needed elements more or less soluble. Sometimes these processes develop harmful substances, which in turn may be made inert by other reactions. These interactions would take place to some extent if there were no microscopic plants or animals in the soil, but as a matter of fact every reasonably good soil is full of bacteria, molds, and minute animal forms. These cause changes that affect crop plants, usually beneficially, sometimes harmfully. Of all these organisms, certain species of bacteria are the ones most useful to crops, and these bacteria live, multiply, and work best when there is plenty of organic matter and enough air and moisture. This organic matter may be supplied by stable manure, by crop residues, or by green manures.

Green plants turned under must decay before they can be completely used by the next crop. Decay is brought about mainly by bacteria and fungi, and the process is somewhat complex. Eventually, however, the mineral substances are set free, and it is an important fact that the phosphorus and potassium derived from decayed plants are more readily available for the next crop than are these substances when derived from mineral soil particles.

The proportions of mineral ash materials in crop plants vary, but are in no case large. Since the quantities present in the green-manure crop are only those previously taken from the soil, the turning under of green manures must not be expected to take the place of desirable additions of phosphate, potash, sulphur, or lime. In the decay of plant tissues acids are produced, and these acting on the soil render parts of the mineral foods soluble.

NITROGEN SUPPLY.

One of the most important functions, if not the most important function of organic matter in the soil, is to keep up the nitrogen supply. Fortunately, an inexhaustable supply of nitrogen exists in the atmosphere. The higher plants, however, can not use directly the uncombined nitrogen of the air.

There are three ways in which the available nitrogen in any particular soil may be increased by the aid of microorganisms which, when carbon is supplied, are able to take the nitrogen from the air or to change organic nitrogen to nitrates. It is probable that at least two of these processes are constantly in operation in all soils whenever temperature and moisture conditions permit. The enormous numbers of these microorganisms make possible a very considerable deposit of nitrates. The three processes referred to may be stated as follows:

(1) Growth of the nodule bacteria in the roots of most living leguminous plants.

(2) Ammonification and nitrification of organic nitrogen contained in the soil. This process is performed by different groups of bacteria, and the result is the formation of nitrates which can be used by crop plants.

(3) Growth of free-living nitrogen fixers. Various bacteria and molds living in the soil can take nitrogen direct from the air, provided they have such materials as starch or cellulose for food.

HOW LEGUMES GET NITROGEN FROM THE AIR.

It was known even in ancient times that much larger crops of various kinds could be produced on land that had been in a legume the previous season. In modern agriculture the value of legumes is generally appreciated, as is seen in the common practice of growing clover or some other legume in rotation at frequent intervals.

An examination of the roots of leguminous plants will reveal on many of them nodules, sometimes very few, sometimes many. (Figs. 1 and 2.) These vary in size and shape according to the kind of plant. Thus, on red clover (fig. 2) they are more or less round or ovoid and

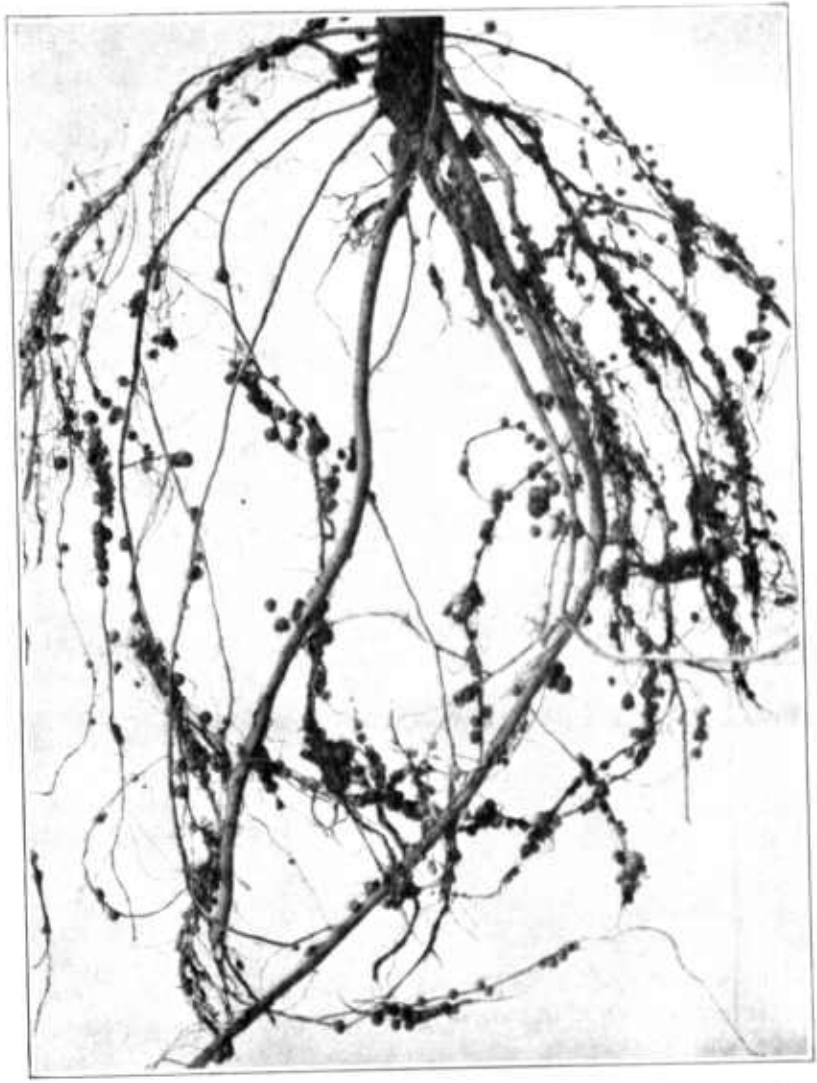

FIG. 1.—Root system of a soy bean plant, showing the nodules which are nitrogen gathering laboratories.

quite small; on the cowpea they are also round and nearly smooth but much larger; on the velvet bean they may reach the size of a pigeon's egg; on the vetches they are irregular both in shape and size.

The differences in the nodules are such that in many cases it is possible to determine by the nodules the plant to which the root belongs.

When leguminous plants have these nodules on the roots they can make use of the free nitrogen of the air; when they do not have these nodules they are powerless to do this, but must obtain their supply of nitrogen from the soil in the same manner as most other plants. These nodules are caused by a certain kind of bacteria and it is really by these bacteria that the nitrogen of the air is absorbed so that it can be used by the clovers or by other legumes. The bacteria obtain their principal nourishment from the legume, while in turn they provide nitrogen from the air which can be used by the host plant. When legumes are grown in rich soil they can take the nitrogen from the soil and thrive without having nodules on the roots. In poor soils, however, especially in such as have little organic matter, the growth of the legume is much reduced when nodules are not present. (Fig. 3.) In such soils it is always necessary before seeding a legume to make sure that the proper bacteria are present.



FIG. 2.—Roots of red clover, showing nitrogen-gathering nodules.

SOIL INOCULATION.

Nearly every legume has its own particular strain of nodule bacteria. For example, that of clover is different from that of alfalfa, and that of the cowpea is distinct from that of the soy bean. In planting a leguminous crop for the first time it will often happen that no nodules will form on the roots, because the proper bacteria are not present in the soil. These may be supplied by scattering

soil from a field where the crop it is desired to sow has been grown recently or by using an artificial culture of the proper bacteria.

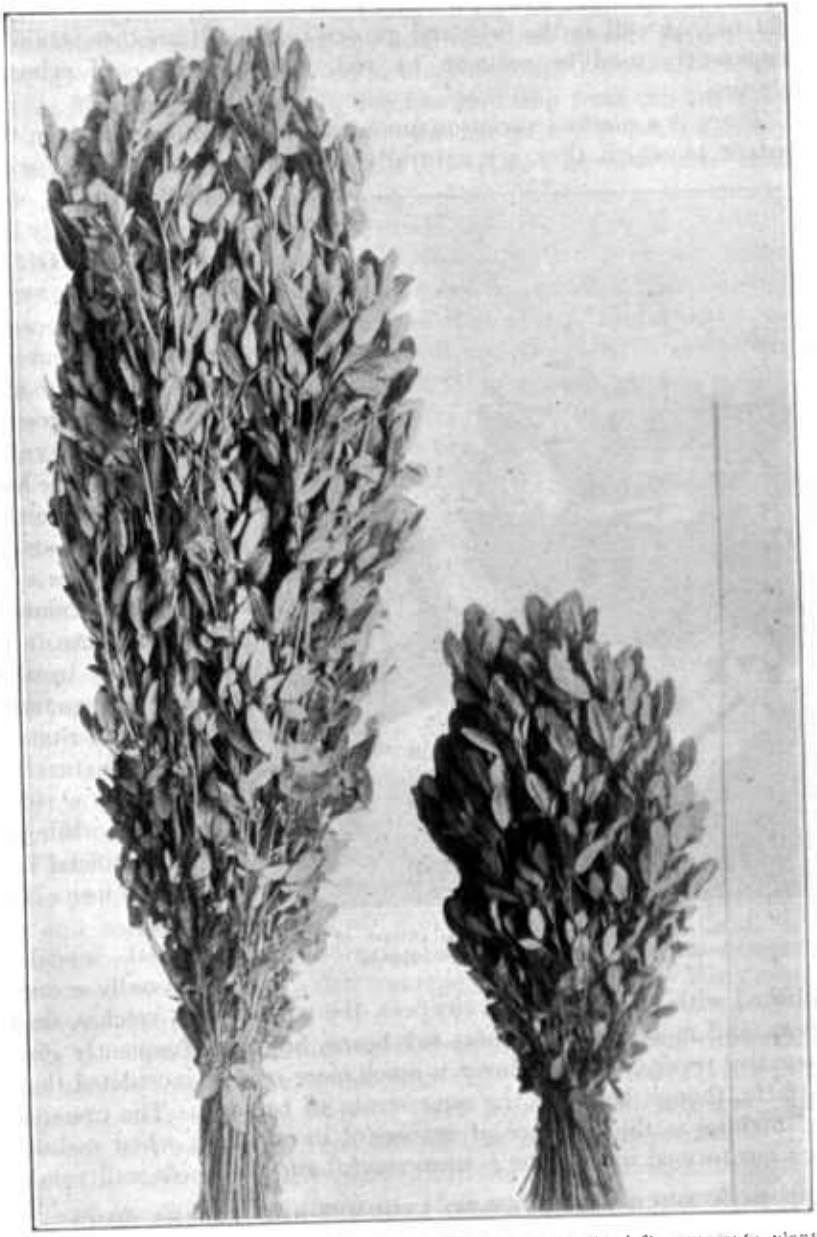

FIG. 3.—Sweet clover grown on poor land. The foliage at the left represents plants that were inoculated, that at the right from adjacent land was not inoculated.

(Fig. 4.) After the field is once thoroughly inoculated there is rarely any difficulty in getting an abundant supply of root nodules.

A strain of bacteria will often inoculate different closely related legumes. Thus alfalfa, bur-clover, and sweet-clover nodules are produced by the same strain; a different strain inoculates most of the vetches, as well as the field and garden peas; still another strain is apparently used in common by red, white, alsike, and crimson clovers.

There is a marked variation among different legumes, both in the extent to which they are naturally noduled and in the ease with which different ones may be artifically inoculated. Natural inoculation presupposes the existence of the proper germs in the soil, and these are nearly always present over areas where a particular legume has been generally grown. Thus, red clover is practically always naturally inoculated in the northeastern and cowpeas in the southeastern quarter of the United States. Alfalfa is naturally inoculated, as a rule, in the West, while in the East artificial inoculation is usually necessary.



FIG. 4.—Mixing seed with an artificial culture of the proper germs to insure soil inoculation.

Artificial inoculation is usually accomplished with ease as regards cowpeas, the true clovers, vetches, field peas, and most other legumes; soy beans, however, frequently give negative results. Sweet clover is much more readily inoculated than alfalfa, though both use the same strain of bacteria. The presence of nodules is the evidence of successful inoculation; when nodules are not formed inoculation is unsuccessful and no benefit will result.

HOW MUCH NITROGEN DO LEGUMES ADD TO THE SOIL?

Attempts have been made to determine the quantities of nitrogen fixed by the action of the nodule bacteria, but no method has yet been found that will give more than an approximately correct answer.

Analyses have been made of the quantities of nitrogen in various leguminous crops, both tops and roots, but the total nitrogen thus obtained includes some that was taken directly from the soil. Determinations have been made of the total nitrogen in soils before and after growing a leguminous crop, but the result represents merely the net difference between gain and loss resulting from the interplay of a number of factors, and even the net gain can not be safely credited to the legume alone. Lastly, certain legumes have been grown with and without inoculation and the difference in the quantities of nitrogen in the crops determined.

The Michigan Agricultural Experiment Station grew soy beans, inoculating the soil on one field and leaving another uninoculated. Samples taken and analyzed showed that about two-thirds of the total nitrogen was taken from the soil and one-third from the air. The Illinois Agricultural Experiment Station grew alfalfa, both in pots and in field plats, some inoculated, others not. On the inoculated plats the alfalfa in the crops for a season contained nearly 160 pounds more nitrogen per acre than the crop from the uninoculated plats.

At the Central Experimental Farm at Ottawa experiments were conducted with red clover by growing this crop year after year on specially prepared plats of sandy soil with a known nitrogen content. All the clover grown was turned back to the soil during nine years. At the end of this time the soil contained 472 pounds of nitrogen per acre more than at the beginning. As a result of a similar experiment carried on by the New Jersey Agricultural Experiment Station, the conclusion seems warranted that in this case the legumes took from the air and made available to the grain crops at least 54 pounds of nitrogen per acre each year.

The Rhode Island Agricultural Experiment Station found that after growing legumes in pots for five years, removing the above-ground portions of the summer crops but turning under the hairy vetch grown in winter, there was a gain at the rate of a ton of nitrogen per acre, seven-tenths of which was removed in the crops. Many more examples might be given.

On the other hand, workers in Kansas and in Wisconsin concluded that alfalfa took more nitrogen from the soil than from the air and that when the hay was removed there was a loss of nitrogen. In general, however, it has been accepted as an approximation to the truth that legumes get about two-thirds of their nitrogen from the air and one-third from the soil. If these crops are turned under, the soil will be richer in nitrogen; if they are removed, there will be in general little or no change in the nitrogen content of the soil so far as this is influenced by the fixation of nitrogen in the nodules and by the removal of the crop.

AMMONIFICATION AND NITRIFICATION.

When plants are turned into the soil certain microorganisms at once cause them to decay. Decay consists essentially in the breaking down of the complex organic compounds into simpler ones. To change organic nitrogen into nitrates requires the cooperation of three distinct organisms, all living together and all commonly working together so harmoniously that one step follows another without interruption. The first set of organisms breaks down the organic nitrogen compounds into ammonia, and under favorable conditions, as in a manure heap, this process may go on so rapidly that ammonia gas passes into the atmosphere and may be detected by the odor. In the decay of green plant material in the soil, however, the ammonia is used by another organism as fast as it is produced or it is absorbed by the soil. The ammonia, in the form of ammonium carbonate, is

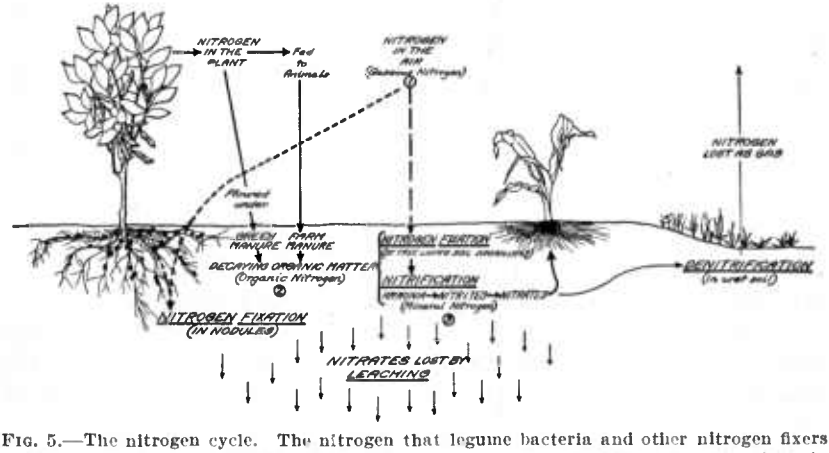

FIG. 5.—The nitrogen cycle. The nitrogen that legume bacteria and other nitrogen fixers take from the air is made available to corn through changes that take place in the soil.

used by nitrite-producing organisms to form nitrous acid, from which nitrites are formed; nitrous acid is a poison to higher plants. There is, however, another germ which uses this product so rapidly that it is difficult to find any of the poisonous product in the soil. This last germ changes the nitrites into nitric acid, which, by combining with a base, produces a nitrate. In this form the nitrogen can be utilized by the higher plants.

Figure 5 shows diagrammatically the processes of the nitrogen cycle. It should be distinctly understood that each change is due to the activity of one or more kinds of bacteria or microorganisms.

NITROGEN-FIXING ORGANISMS.

Besides the nodule germs and the ammonifying and nitrifying germs there are other organisms, bacteria and fungi, living free in the

soil which have the power to fix atmospheric nitrogen. The organism of this class most commonly mentioned is called Azotobacter, though this form is but one of several that seem to have the power of fixing in the soil the nitrogen of the air without living in the roots of plants. The organisms of the Azotobacter type thrive in the presence of oxygen, but another type of nitrogen-fixing germ known as Clostridium can fix atmospheric nitrogen only in the absence of oxygen. All of these organisms, however, must have a source of carbon, and the cellulose which makes up the cell walls of plants and whatever starch may be in the plants turned under serve as sources of carbon, so that the growth and activity of these nitrogen-fixing forms is directly dependent upon a liberal supply of organic matter in the soil. How much nitrogen the organisms of this type fix is not known.

The Illinois Agricultural Experiment Station has shown that in the experiments there conducted Azotobacter fixed 15 pounds of nitrogen while using the carbonaceous material in 1,212 pounds of fresh clover tops or in 5,500 pounds of corn stover. Our knowledge of this group is still very imperfect, but it is clear that these organisms using the carbon in organic matter for food play a significant part in maintaining the nitrogen supply of the soil.

RATE OF DECOMPOSITION OF GREEN MANURES.

Very little is known about the exact rate of decomposition of green manures under field conditions, as measured by the production of nitrates. By laboratory experiments it has been found that when legumes are turned under fresh considerable quantities of nitrate may be produced after 2 to 4 weeks. The maximum production seems to take place from 4 to 12 weeks after the green material has been placed in the soil under favorable conditions of temperature and moisture. Dried or cured material is much slower to start and lags behind the fresh material in the production of nitrates as much as 80 to 100 days. In Delaware it was shown that dried plant material when plowed under in spring might remain in the soil practically unchanged until August and so would be of no use to the corn crop for that season. However, in warm, moist, sandy soils even dead plant material if turned under early and well disked and chopped is said to have benefited cantaloupes, tomatoes, sweet potatoes, and even corn. Fresh clover turned under in May has been shown to provide nitrates for the corn crop that year. The rate of decomposition depends, of course, on the character of the soil and the nature of the plants turned under. Legumes decay more rapidly than the grains or grasses. In a loose, warm, moist soil decay will be more rapid than in a cold, stiff, or dry soil.

EFFECT OF LIME ON DECAY AND ON NITRIFICATION.

Lime generally stimulates decay and nitrification. Many laboratory experiments have shown that the production of nitrates goes on most rapidly in well-limed soils. In Pennsylvania, however, it was found that there was abundant nitrification in soils with high lime requirements.

Both the caustic form and carbonate promote the well being of the soil organisms concerned in the decay of plants. Lime in caustic form, however, when applied in large quantities may destroy these bacteria, and it favors the evolution of ammonia to an undue degree. Some experiments have shown that when a green-manure crop is turned under and burnt lime applied there is an actual loss of nitrogen. Lime in the carbonate form is useful, since the bacteria that change ammonia to nitrites can use only ammonium carbonate. When the ammonia is produced, therefore, some form of carbonate must be present from which the ammonium carbonate may be formed or the second step in nitrification can not take place. The carbon dioxid from the decomposition of organic matter probably is an effective agent for the formation of ammonium carbonate. On land that does not need lime for the growing of clover there will be nothing to gain by adding lime when the green-manure crop is turned under. When land needs lime the better practice will be to add this at a time when it will do most good to the legume crop.

LOSS OF NITROGEN.

It is important to know that under certain conditions nitrogen may escape from the soil as a gas. This result is brought about principally by certain organisms, called denitrifying bacteria, that break up nitrogen compounds and permit the nitrogen to escape, usually in the form of gaseous nitrogen. While the details of this process are imperfectly known, it is clear that large losses are likely to occur when abundant decaying matter is present, together with high temperature and lack of air. Such losses occur particularly in rich water-logged lands and in manure heaps. For these reasons it is not good practice to endeavor to obtain a large store of nitrogen in the soil beyond the needs of the crops. For the same reason green-manure crops should not be used on poorly drained lands. According to the English authority E. J. Russell, green manures in swamp and paddy soils in India, China, and Japan serve as sources of oxygen to the rice roots and in this way perform a valuable function. Data as to the value of green manures on rice lands in America are wanting.

Another source of loss is the leaching of nitrates from the soil. Under favorable conditions nitrates are constantly being formed, and

since they are readily soluble they are leached out of the soil unless growing plants are present to absorb them. This fact makes it important to consider the time for turning under green crops and for planting cover or other crops to consume the nitrates that are to be produced.

COMPOSITION OF GREEN-MANURE CROPS.

The essential fertilizing substances added to the soil as manures are nitrogen, phosphorus, and potash. Table I gives the proportions of these substances in both the tops and roots of several legumes, as shown by a number of analyses of each.

TABLE I.—*Fertilizing materials in 100 pounds of dry substance.*

[Compiled from various sources.]

Plant and part.	Critical fertilizing substances (pounds).			Plant and part.	Critical fertilizing substances (pounds).		
	Nitrogen.	Phosphoric acid.	Potash.		Nitrogen.	Phosphoric acid.	Potash.
Red clover:				Cowpea—Cont'd.			
Tops	2.56	0.72	1.40	Roots	1.19	0.67	1.94
Do	2.07	.38	2.20	Do	.68	.64	1.16
Do	1.97	.56	1.86	Do	1.46	.16	.77
Do	2.81	.65	3.10	Do	1.40	.73	.76
Do	2.74	.84	.82	Soy bean:			
Roots				Tops	2.06	.80	1.20
Alfalfa:				Do	2.32	.67	1.08
Tops	2.42	.58	1.42	Do	2.97	.55	1.98
Do	2.30	.53	1.46	Do	2.00	.65	2.23
Do	2.19	.51	1.68	Do	1.53	.57	1.76
Do	2.04	.43	.48	Do	2.01	.65	2.17
Roots				Do	1.75	.40	1.32
Crimson clover:				Do		.81	.36	.90
Tops	2.38	1.10	1.56	Roots	1.22	.32	.24
Do	2.05	.40	1.31	Do	1.11	.35	.87
Do	1.95	.36	1.17	Do	2.51	.53	3.84
Roots	1.50	.47	1.02	Velvet bean			
Cowpea:				Common vetch:			
Tops	2.32	.51	2.92	Tops	3.53	.74	2.56
Do	1.81	.65	1.29	Do	3.18	.77	3.50
Do	1.59	.30	1.53	Do	2.27	.62	1.97
Do	1.95	.52	1.47	Do	2.19	.79	1.18
Do	1.75	.45	1.27	Roots	3.02	1.26	4.68
Do	2.23	.57	2.00	Rape	1.07	.50	1.70
Do	2.09	.56	3.04	Rye hay	.99	.31	1.36
				Timothy			

It has been found that all plants vary widely in the relative quantity of these materials they contain. The same plant varies when grown on different soils or in different seasons on the same soil. In Table I it will be noted that the variation in legumes as regards phosphorus and potash is nearly as great in any one legume as it is between different legumes.

SHOULD GREEN CROPS BE TURNED UNDER, FED, OR SOLD?

The question will be raised whether it is more profitable to turn under a growing crop for green manure, to feed it on the farm, or to

sell it as hay. No specific answer can be given, as in every case many local factors will be involved. (Fig. 6.)

Theoretically, there is no doubt that the returns will be greater when crops can be advantageously fed to animals and the manure used on the farm than when the crop in question is turned under, but the theoretically ideal conditions seldom occur. While it is true that mature horses may void nearly or quite all of the fertilizer substances contained in the feed and milk cows 75 to 80 per cent, it is also true that the greater part of this is usually wasted before reaching the land. The maintenance of the organic matter in the soil is an important element in the economy of the farm, but probably not more than 15 to 30 per cent of the organic matter in a hay crop is returned to the soil in the manure. The nitrogen in green-manure crops is also more readily available than that in stable manure. The readiness with which any source of nitrogen supplies this element to plants is called its availability. Lipman rates the availability of the nitrogen from green manure at 65 as against 25 for stable manure. Wheeler rates nitrate of soda at 100, green manure at 70, and stable manure at 45.

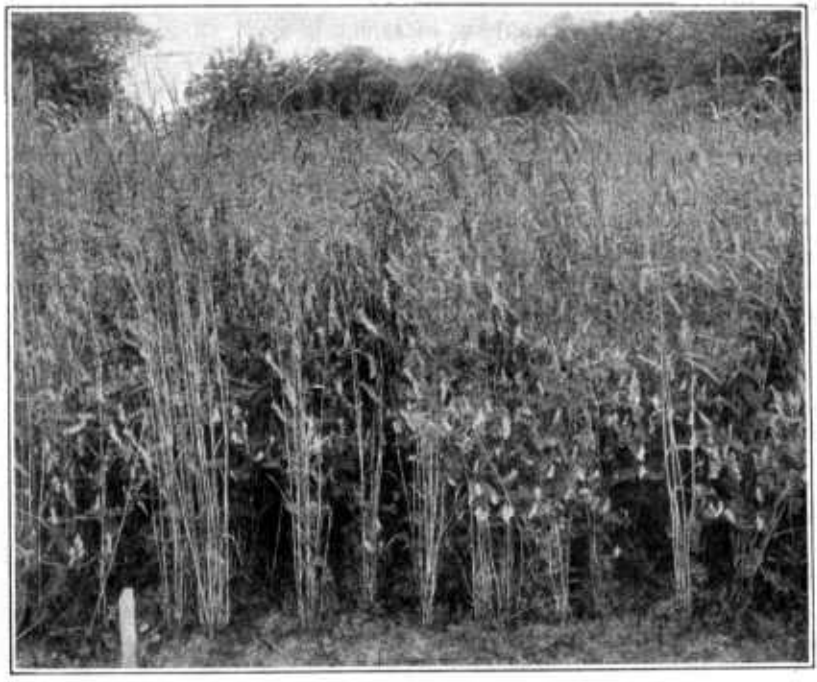

FIG. 6.—Hairy vetch and rye, the best green-manure crop for the North. Is it worth more than hay?

Owing to the wide variations in the quality of stable manure and in the composition and quantity of green manures that may be produced per acre, as well as the cost of commercial fertilizers, a detailed discussion based on hypothetical cases would have little value. It may be suggested, however, that the question of the profits from feeding live stock must rest on the returns from that industry and not on the value of the manure. The benefits from turning under a green crop will certainly be greater than if the manure made from this crop alone is returned to the soil.

The relative values of a crop when sold or when turned under can be expressed somewhat more definitely, though in this case also economic considerations wholly apart from the value of the crop as green manure or as hay will doubtless control. As shown in Table I, plants contain certain quantities of nitrogen, phosphoric acid, and potash. The proportions vary in different crops and even in the same crop, but it is not difficult to determine a general average. According to the average of the figures in Table I, 47 pounds of nitrogen, 11.6 pounds of phosphoric acid, and 42.8 pounds of potash are taken from the farm when a ton of red clover hay is sold. These substances have a market value for which a farmer has to pay if he buys them in commercial fertilizers. The greater part of a green-manure crop, however, consists of organic matter. This organic matter has a value both from its influence on the physical condition of the soil and as a food for microorganisms which will, while consuming it, fix atmospheric nitrogen.

The entire argument may be summed up as follows: Where a forage crop can be grazed or advantageously fed and the manure returned to the land this will be found most profitable. Where insufficient live stock is kept or where the soil is poor and in need of organic matter, a green crop may often be worth more in the long run if turned under than if sold. On the other hand, the Georgia Agricultural Experiment Station in a green-manuring experiment with cowpeas and cotton in 1894 showed that the financial returns for three years were greater where the cowpea vines were made into hay and the stubble turned under for cotton than where the whole crop was turned under. The Georgia station took no account, however, of the increased yield to be expected from the second and even the third crop after turning under an entire legume crop. The Alabama Agricultural Experiment Station and the Central Experimental Farm at Ottawa have shown that such later increases may be expected when the entire legume crop is turned under, but not when the stubble only is used. Whether these increases would pay for the sacrifice of a hay crop in any special case can not be estimated here. The data are too fragmentary for even general conclusions. It is known that the

turning under of a green-manure crop may affect the yield of subsequent crops even to the third year, and this fact should have weight when the question of selling a legume hay crop or turning it under is considered.

EFFECT OF A GREEN-MANURE CROP ON THE YIELD OF A SUBSEQUENT CROP.

The value of any particular soil treatment must be determined by the yields of crops resulting from the treatment. In the United States many records show that the turning under of a green-manure crop will increase yields, but none of these tests have been made in such a way as to make possible a definite answer to the questions raised in the preceding section or to throw exact light on the relative value of different green-manure crops. Experimental work on green manuring has been largely confined to the South, the Atlantic seaboard, and to portions of the Pacific coast, with scattering tests in other parts of the United States and in Canada.

In Table II the results of some of the work at the Alabama Agricultural Experiment Station have been brought together as illustrative of what green manuring will do under the conditions prevailing in each experiment. It must be added that there are also records of the failure of green manures to produce increases in the crops that follow them. Such records are most common from the Ohio and Mississippi Valleys and from the West. There is also evidence to show that certain crops are either injured or benefited by a preceding leguminous crop, depending upon the nature of the legume. This will be considered further on pages 27–28.

TABLE II.—*Effect of green manures on crop yields in Alabama.*

Preceding crop.	Yields per acre.		
	Seed cotton.	Corn.	Sorghum.
	Pounds.	*Bushels.*	*Pounds.*
Cotton	837		
	918	18.0	
Cowpea vines turned under	1,533		
Velvet-bean vines turned under	1,373	25.9	
	1,579		13,440
Velvet-bean stubble	1,126		
Oat stubble	342		
Crimson-clover stubble	456		9,750
Crimson clover (ripe) turned under	528		10,300
Corn		13.6	
Rye stubble			5,525

The North Carolina Agricultural Experiment Station grew wheat in 1888–89 and in 1889–1900 on 14 plats, on 7 of which cowpeas had

been turned under and on 7 of which there had been no cowpeas. The average yield per acre is shown in Table III.

TABLE III.—*Effect of cowpea vines turned under upon the yields of wheat in North Carolina.*

Crop year.	Yields per acre.			
	With cowpeas.		Without cowpeas.	
	Bushels.	Pounds.	Bushels.	Pounds.
1888–89	25	47	15	54
1889–1900	20	52	6	9

Red clover has been used as a catch crop by the experiment stations in Canada and in Minnesota. The results from some of these trials are given in Table IV.

TABLE IV.—*Yields after turning under a catch crop of red clover in Canada.*

Previous crops.	Yields per acre.		
	Oats.	Fodder corn.	Potatoes.
	Bushels.	*Tons.*	*Bushels.*
Wheat:	63.53	16.40	353.33
No clover	72.94	22.80	386.00
Clover			
Barley:	61.18	17.36	346.67
No clover	70.59	23.60	386.33
Clover			
Oats:	58.88	15.00	358.33
No clover	70.59	20.40	392.67
Clover			

That a legume green-manure crop can replace certain quantities of nitrate of soda has been shown by several experiment stations. Table V gives the result of a trial in California.

TABLE V.—*Results from turning under legumes in California.*

Previous crops.	Yields per acre.		
	Corn.	Potatoes.	Beets.
	Bushels.	*Bushels.*	*Tons.*
On all legume plats (average)	40.00	226	17.9
Barley plats:			
Without nitrate of soda (4 plats averaged)	30.00	161	12.3
With 270 pounds of nitrate of soda	32.00	166	12.5
With 540 pounds of nitrate of soda	42.00	204	15.7
With 810 pounds of nitrate of soda	34.00	191	16.0
With 1,080 pounds of nitrate of soda	41.00	218	17.7

The practice of sowing crimson clover in corn and turning under the clover for the next corn crop is frequently followed on suitable

soils from Delaware to the Gulf of Mexico. A case showing the results that may be obtained is reported in Farmers' Bulletin 1121. In this instance the soil was made to produce nearly three times as much corn every year as it had produced once every third year. (Fig. 7.) Under favorable climatic conditions a cultivated crop may be grown every year by seeding crimson clover in the standing crop in late summer and turning it under the following spring for the next crop.

MOISTURE AND A GREEN-MANURE CROP.

A growing crop removes moisture from the soil, and this removal of moisture may reduce yields. In the South it has been found that cowpeas grown with corn often reduce the yield of corn for that year. This is believed to be because the moisture is not sufficient for both the corn and the cowpeas. In the peach section of Michigan a winter cover and green-manure crop is wanted that will make a good growth in late August, so as to draw the moisture away from the trees and force the ripening of the wood. In Nebraska the orchard cover crops recommended are such as are killed by the first frost, others, such as rye, taking too much moisture from the ground in late winter and early spring.

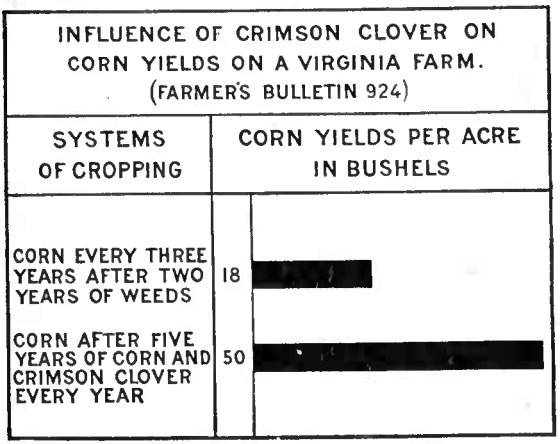

FIG. 7.—Results of growing crimson clover to increase the corn yield on a farm in Virginia.

In the South, East, and North, green-manure crops are commonly turned under at a time when the supply of moisture is ample for decay, but if a dry spell should follow the turning under of a heavy crop of green matter the soil should be well rolled and compacted to prevent drying out. In the semiarid parts of the West and Northwest moisture is the limiting factor in crop production, and any practice that reduces the moisture supply of the main crop is to be avoided. The Office of Dry-Land Agriculture Investigations of the Bureau of Plant Industry has found that green-manure crops which make their growth so as to be turned under late are usually injurious. They not only take up the soil moisture while growing but absorb large quantities when turned under and leave the soil more porous

and exposed to drying than before. If, however, a crop like rye can be turned under early, before the close of the rainy season, some benefit may accrue, since the green manure will hold the extra moisture and help prevent the drying of the soil.

EFFECT OF A GREEN-MANURE CROP ON SOIL ACIDITY.

It is often said that the turning under of large masses of green plant material will sour the soil. In northwestern Ohio some good farmers prefer to allow the mammoth or second-crop red clover to become ripe and dry before turning under, claiming that in this condition it does not cause soil acidity. Enough authentic reports are of record to show that the turning under of a heavy green crop may depress the yield of a crop immediately following. It has been suggested that this may be due to a temporary decrease in the supply of available nitrates. Experiments have shown that in the presence of large quantities of food material, such as may be found when masses of succulent plants are turned under, there may be an enormous increase in the numbers of bacteria, especially the putrefactive ones. These may then consume the nitrates as fast as produced and even decrease the available nitrogen in the soil. However, our information on this point is at present limited. 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 on increasing the lime requirement of soils.

FERTILIZING THE GREEN-MANURE CROP.

The object in growing a green-manure crop is to produce as much material as possible to turn under. On very poor soils it frequently happens that even the strongest feeders can make but a poor growth, and consequently the benefit from the crop is decreased. Even cowpeas will sometimes make only a poor growth unless the plants are stimulated by an artificial fertilizer. When a legume is grown the addition of nitrogen is not usually necessary, as the legume will gather its own nitrogen, but an application of phosphorus and potash often increases the crop greatly and thus enables the plant to gather more nitrogen. The phosphorus and potash that may be applied for the benefit of the green-manure crop is not wasted either, as it will all be available for the next crop when the green-manure crop decays. What fertilizer and how much should be used will depend on the soil and on the crop, but generally 300 to 400 pounds of 16 per cent acid

phosphate and 100 pounds of muriate of potash per acre will be found to stimulate the growth of the green manure so as to produce a larger crop than could have been grown without the fertilizer. The larger crop, if a legume, will gather more nitrogen than a small one could, and the soil will receive correspondingly greater benefit. It is also good practice to apply stable manure to specially poor spots, so as to encourage a good growth and thus bring the field up to a more uniform productiveness.

COVER CROPS.

A cover crop may be defined as one grown between or among regular crops and seeded for the purpose of protecting the soil or the roots from the action of the weather. A cover crop is often a green-manure crop, and the term "cover crop" as often used is exactly synonomous with a green-manure crop. Crimson clover, for example, when grown for a winter green-manure crop is also a cover crop, and writers often call it such. Its function in such a case is twofold: It covers and protects the ground and when turned under serves as green manure. Such a crop should be spoken of as a cover crop when its primary purpose is to afford protection, and as a green-manure crop when its primary purpose is soil improvement. As a matter of fact the two ideas can not be sharply separated. A crop of cowpeas grown in summer for turning under that season is a green manure and not a cover crop, though it protects the ground quite as effectively against summer rains as the crimson-clover cover crop protects it against winter rains.

A cover crop may be an orchard cover crop or one for open fields and may or may not be later used as a green-manure crop. The term "orchard cover crop" is easier to define than the general term "cover crop," for the primary idea is to benefit the trees by helping to ripen the wood and by protecting the roots. It is a crop sown among trees after the period of active spring growth has passed and turned under the next season before or about the time active growth begins. An orchard cover crop is designed to benefit the trees and will vary in character not only with the locality but also with the kind of trees in the orchard. In the Eastern States an orchard cover crop is wanted that will check the growth of trees in the fall and ripen the wood, cover the ground during the winter to hold snow, to protect the roots from freezing, to prevent leaching, and on some soils to help dry out the ground in early spring. For the last purpose a live crop is wanted, and if this is later turned under it becomes a green-manure crop. It must be noted, however, that many experienced orchardists in the East consider the drying of the ground in spring by a live cover crop a danger. It is a

necessary evil connected with such cover crops as rye and crimson clover and may have serious results if not guarded against. For this reason such a crop must be turned under early; rye should not be allowed to get more than a foot or so high. In many cases a legume is selected for the purpose of adding nitrogen to the soil. Some authorities recommend sowing mixtures of a small grain, hairy vetch or clover, and rape or cowhorn turnips. The rape or turnips will die during the winter, but in spring the grain and the legume can be turned under as a green-manure crop. It has been recorded in New York that clover stimulated the growth of peaches too late and thus made them susceptible to winterkilling. The crops used will need to be selected to meet the purposes for which they are most wanted. In Nebraska an orchard cover crop is never a green-manure crop, since crops that remain alive during winter are not wanted. They dry the ground too much in spring.

In the citrus and walnut orchards of California the growing of cover crops for green manures has come to be a general practice. Discussing the qualities desired in a green-manure crop in this section, McKee (U. S. Department of Agriculture, Bureau of Plant Industry Bulletin 190, p. 11) says:

> A green-manure crop should be a legume wherever possible, in order to obtain the addition of nitrogen to the soil. It is also necessary that a good growth be made, in order to have a large quantity of organic matter to turn under and incorporate with the soil. Along with good growth should be a heavy development of nodules on the roots, as this is believed to indicate great ability to fix atmospheric nitrogen.
>
> The quality of being able to stand trampling with a minimum of injury is very important where the crop will be subject to such injury, as is the case in citrus orchards where the picking of fruit takes place while the green-manure crop is yet growing. Uprightness and nontwining stems are also desirable where an ordinary moldboard plow is depended upon for turning under the crop. However, if a disk plow is used or the crop is worked in with an ordinary disk harrow, this does not make so much difference, and where the growth is not allowed to become too rank little difficulty is experienced in plowing it under.
>
> The texture of the stem should be such as to decompose readily. Practically all crops, however, if turned under at the right stage of growth decay readily. Thus, the question of decomposition is one of turning under the crop at the right time rather than one of selecting a crop that will decay readily.
>
> That the cost of a green manure may not be too great, it is necessary that the price of seed be reasonable as compared with the results to be obtained.

Some years ago common vetch and field peas were the crops most generally used, but to-day the yellow annual melilot, or sour clover, has largely replaced the peas. The sour clover is not wholly satisfactory, but the seed is cheap. The purple vetch will probably become the chief green-manure crop in this section as seed becomes more abundant and cheaper.

The best practice in the East and South at least demands that the ground shall be covered with a growing crop as much of the time as possible. Catch crops and cover crops are used to occupy the ground

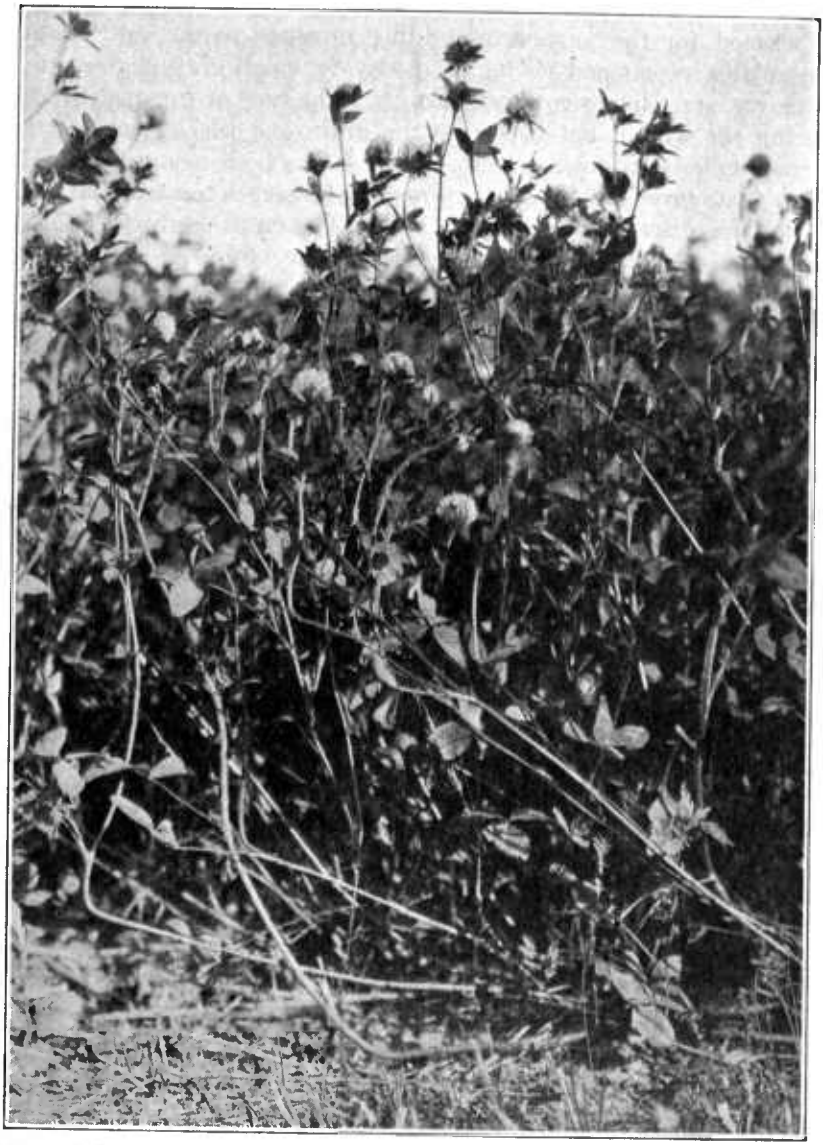

FIG. 8.—Mammoth clover, an excellent green-manure crop. Some farmers prefer to turn this crop under when it is ripe or after the seed is harvested.

between main crops. In the South such a crop should, so far as possible, be a legume. Crimson clover, bur clover, or hairy vetch should be planted in the fall to grow during the winter and be turned

under for the benefit of the next crop. In some parts of the South red clover can be used in this way.

In the potato-growing section of New Jersey the practice of growing a cover crop is especially extensive. Writing of the potato industry in New Jersey, Frank App (New Jersey Agricultural Experiment Station Bulletin 295) says:

> The basis and means of maintaining such an intensive industry depend to a large extent on the universal use of cover crops. * * * 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 the cover crops are skillfully handled.

Rye and crimson clover, either separately or in mixture, are most used, although the use of wheat instead of rye is not uncommon. After early potatoes a cover crop may be used or the field may be laid down for hay. After the main crop a cover crop of clover or rye may be seeded, while after the late crop only rye can be used. According to App, cowpeas are sometimes seeded on light sandy land after an early potato crop and are later plowed under and followed by rye. Alsike clover has been used quite successfully in some sections of New Jersey; but both alsike clover and mammoth clover, since they do not start growth so early, must be allowed to stand later in spring than crimson clover. (Fig. 8.)

In the North, outside the Atlantic coast region, hairy vetch is practically the only legume that can be seeded in the fall and make enough growth to turn under in the spring. In Indiana crimson clover is successful only under especially favorable conditions, as on sandy soil, and it can not be generally recommended as a safe crop north of the Ohio River. In Pennsylvania it is reliable only in the extreme southeastern part of the State. Hairy vetch and rye (fig. 6) make a good combination, the latter making a fair growth in the fall and thus preventing the washing of the soil. Buckwheat, rape, and cowhorn turnips are highly recommended in some sections, but they can not serve as cover and green-manure crops to be turned under in spring, as they will not survive the winter. A mixture of half a bushel of seed of wheat or rye, 15 pounds of hairy vetch, and 6 pounds of crimson clover has been successful in New Jersey. A summer cover crop is sometimes used to follow an early crop. In this case such crops as cowpeas, soy beans, buckwheat, rape, turnips, or various combinations may be seeded and turned under for wheat or rye in the fall.

TYPES OF GREEN-MANURE CROPS.

Green-manure crops may be considered as of four types:

(1) Those occupying the ground exclusively throughout the summer. This type of green-manure crop is naturally the most expensive, since no crop can

be removed from the field that season. A green-manure crop of this sort is seldom to be recommended except where very poor soil must be brought to a state of sufficient productivity to allow a regular rotation to be established.

(2) Subsidiary crops, those seeded with a main crop, such as clovers in grain, and turned under in the fall or the following spring. Such crops involve little extra expense besides seed and may even be grazed moderately without serious harm. The Central Experimental Farm in Canada showed that such crops may be very beneficial.

(3) Stubble crops, those seeded on grain stubble after harvest for turning under in the fall or spring. Cowpeas, soy beans, vetch, buckwheat, rape, turnips, and such crops are most commonly used in this way.

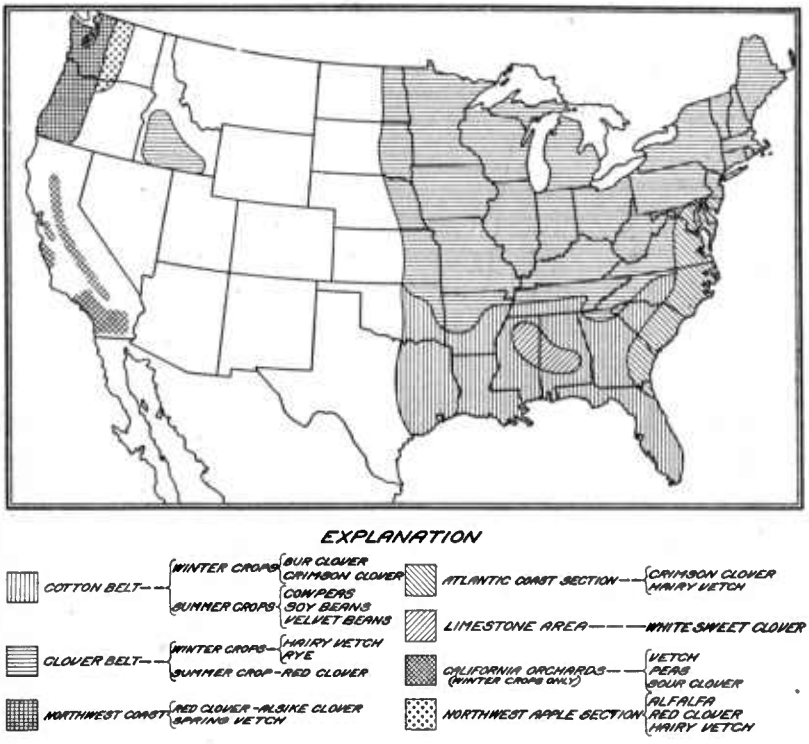

FIG. 9.—Outline map of the United States, showing general green-manure areas.

(4) Winter cover crops. For this purpose crops must be selected that will endure the degree of cold common in the locality. In the South and on the Atlantic seaboard, crimson clover and hairy vetch are most commonly used, but alsike clover and mammoth clover have also been successful in the northern part of this area. Bur clover is a standard winter legume in the cotton belt. Rye and winter oats are also used in the South, especially on soils where it is hard to get a good catch of clover. In the North rye or rye and hairy vetch are most successful.

REGIONAL DISTRIBUTION OF GREEN-MANURE CROPS.

In a general way green-manure crops may be considered with reference to their use in the South, the North, on the Middle Atlantic seaboard, and in the irrigated orchards of California.

In the cotton belt both winter and summer green manures may be used. For the former bur clover, crimson clover, and vetch are well suited; for the latter cowpeas and velvet beans are almost universally used, while beggarweed is locally important, especially in Florida. The benefits from green manuring have been most striking in the South, where yields on run-down lands have been greatly increased by this means. Figure 9 shows approximately the extent of the green-manure sections. It must not be inferred that the crops mentioned are confined to or are the only ones used in the sections named. The map is simply meant to show the sections where these crops are the mainstay in the bettering of yields by green manuring. In the area which is left white, green manuring is not practiced except in an incidental way, as the plowing up of old alfalfa fields.

On the middle Atlantic seaboard, crimson clover is the chief green-manure crop; in the North, red clover and alsike clover, although not often sown especially for green manure, are used in rotations, and the fall and spring growth when turned under adds a considerable quantity of green matter to the soil. Hairy vetch and rye also are used extensively for green manure. In the western part of this area sweet clover has of late years become one of the most important soil-improving crops.

In California green manuring is important only in the irrigated-orchard sections. Here the seed is planted in the fall, and the crop makes its growth during the winter. During the summer the soil is kept cultivated after the green-manure crop is turned under. The crops that have proved best in southern California are all legumes; vetch and field peas were in recent years most commonly used, but the use of the yellow annual melilot and vetch has become more common. In the apple and pear orchards of Oregon and Washington alfalfa is the commonest green-manure crop, but vetch or red and alsike clovers mixed are often used.

CROPS TO FOLLOW GREEN MANURES.

The full results of a green manure are obtained only after it is completely decayed and the mineral elements changed into soluble forms. This requires some time, so that the beneficial results often extend over two or more seasons. When a green crop is turned under in late spring nitrification may go on so rapidly that in 45 days maximum nitrification may be reached.

Generally speaking, cultivated crops are the best to follow green manures. The tillage of such crops hastens the decay of the vegetable matter and by aerating the soil favors additional nitrogen fixation by the soil bacteria. Corn, cotton, and potatoes on most soils derive great benefit when following green manures. Rye and oats are likewise good crops to use in this way. Wheat and barley give varying results, often favorable, but sometimes show no increase, and occasionally a loss is shown. This is especially true the first season following a green-manure crop.

That the proper succession of crops may be a matter of importance has been shown by the Rhode Island Agricultural Experiment Station. According to these studies one crop may have a specific influence on another, making it undesirable as a preceding crop. While these studies have not been carried far enough to enable us to draw conclusions, it seems clear that the proper succession of crops, especially in intensive farming or in the growing of truck crops, should be carefully considered.

At the United States Department of Agriculture Tobacco Experiment Farm it has been found that the growth of tobacco is greatly inferior after soy beans, but that cowpeas, hairy vetch, and red clover are beneficial. Corn is benefited by soy beans. Grass injures tobacco, corn, and potatoes.

WHEN TO USE GREEN MANURES.

Green manuring in some form should be part of the regular farm practice on most of the farms east of the one hundredth meridian and on irrigated land elsewhere. This does not mean that the production of regular crops for sale or consumption should be sacrificed, but that rotation should be so arranged as to work a green-manure crop of some kind between regular crops. Summer green manuring can be recommended only on poor soils, the returns from which must be temporarily sacrificed in order to improve the land, or on sandy, clay, or adobe soils to improve the physical texture. In orchards, too, the summer green-manure crop is profitable, as it does not interfere with the main or fruit crop and is even beneficial to the trees. Attention has been called to the evidence that green-manure crops will increase yields and also to the fact that, so far as any exact observations are of record, it would appear that the value of the increased yields does not usually equal the forage value of the green-manure crop. This fact makes it inadvisable, as a rule, to sacrifice a summer crop for green manure. Green-manuring crops should, however, be grown as catch crops, seeded with or after a grain crop or after potatoes or other crops that can be harvested in time for seeding. If a legume can not be seeded early enough, rye should be used, or a

legume like sweet clover on suitable land may be seeded with grain in the spring and turned under for corn the following spring; this practice is very successful in Illinois. The annual white sweet clover may be used and turned under in the fall. Red clover might be used in the same way, but the growth to be turned under will not be as heavy as for sweet clover, and the stand, if obtained, is likely to be more valuable in the regular rotation; in fact, on good soil where the rotation includes clover every third year the need of a green-manure crop will not be so often felt. This is especially true where such land is kept in good shape by the addition of lime or phosphates, where these are needed. By this means the legume crop is stimulated to a better growth, the root development is better, and more stubble and crop residues are left to furnish organic matter. About one-third

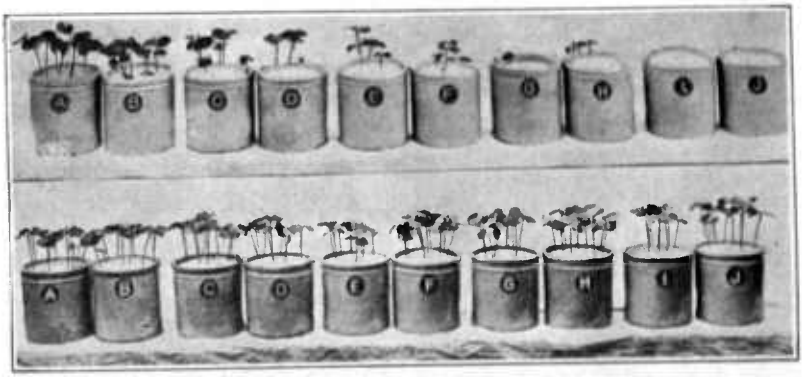

FIG. 10.—Pots of plants, showing the effect of sowing cotton seed immediately after turning under a green-manure crop. In pots C to J of both rows green manure was turned under; seed was placed in the soil of the upper row at once, in the lower row after two weeks.

of the weight of the red-clover plant and about half of that of alfalfa is in the root, so that when these plants or sweet clover are used in the rotation the income from the land need not be sacrificed for the sake of growing a green-manure crop.

The use of green manures in dry farming in semiarid regions is as a rule impracticable, as with insufficient moisture vegetable matter decays very slowly. The soil is thus filled with air spaces and loses much water by evaporation.

WHEN AND HOW TO TURN UNDER A GREEN-MANURE CROP.

Though no definite dates can be given for the turning under of a green-manure crop, certain general considerations will govern. To be useful to the next crop a green crop must decay, and for this, moisture is essential. In the process of decay certain substances are

produced and it has been found that during the early stages of decay the effects on seed planted too soon after the green crop is turned under may be injurious. Figure 10 shows the effect on the germination of cotton seed when planted as soon as the green manure has become mixed with the soil. Pots A and B had no green manure; C and D had green manure at the rate of about 2,500 pounds per acre; E and F, 5,000 pounds; G and H, 10,000 pounds; and I and J, 20,000 pounds of green manure per acre. The seeds in the upper row of pots were planted at once. Note that where only 5,000 pounds per acre were turned under the germination was reduced, and where 10,000 pounds were used, which is only a small



FIG. 11.—Plowing under a crop of crimson clover. This crop should have been turned under at least two weeks earlier for the best results with cotton. (See also fig. 10.)

green-manure crop, the stand was nearly a failure. In the lower row of pots the treatments were the same as in those of the upper row, but the seed was planted two weeks after the green manure was turned under.

A green-manure crop, therefore, should be turned under at least two weeks before the next crop is planted. This depends, of course, on the quantity of green stuff plowed under and on the crop to follow; cotton seedlings, for example, are more sensitive to injurious substances than corn seedlings. (Fig. 11.)

Although the time when a given crop must be plowed under may depend largely on other considerations than the maturity of the green-manure crop, the fact that such a crop may increase greatly in value during the later stages of growth should not be overlooked. The Delaware Agricultural Experiment Station showed that the

gain in nitrogen made by a crop of crimson clover during the month before full bloom depended on the thickness of the stand and the richness of the soil in nitrates. The plants of a thin stand on poor soil acquired the larger part of their nitrogen during this month and should therefore be allowed to stand as long as possible, while those of a thick stand, especially on soil that had frequently grown clover and was consequently well supplied with nitrates, increased little in nitrogen during this time and might as well have been turned under early. In orchard work in Delaware, Maryland, and adjacent States, crimson clover will necessarily have to be turned under before the maximum quantity of nitrogen has been gathered. If left after the flower buds appear it takes moisture from the soil and trees, so that the land becomes unnecessarily expensive to plow, and decay processes are also pushed too far forward in the season for maximum twig and fruit growth.

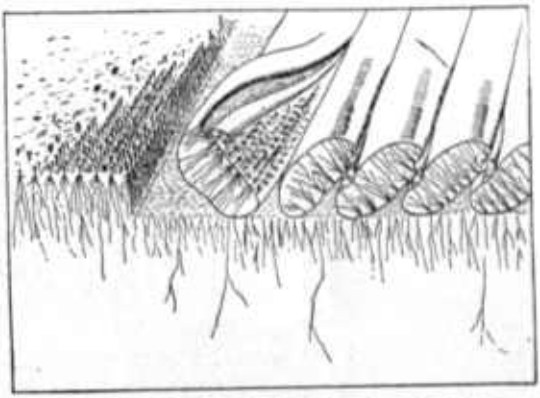

FIG. 12.—Section of plowed land, showing the correct proportions and position of the furrow slice as left by a moldboard plow. The effect of the jointer in turning under the edge of the furrow slice as well as the position of turned-under vegetation is apparent. Do not turn the furrow slice flat; leave it on edge. (From Lyon and Fippin.)

The effect which the time of turning under a green crop may have on the loss of nitrogen should be considered. When a green crop is turned under in the fall for corn the following year there may be some loss of nitrogen in the late spring before corn is planted. However, labor considerations also will help to govern this matter. In some parts of the corn belt farmers prefer to plow in the fall, because the land is cold and wet in the spring and fall plowing enables them to reduce the rush of spring work and to get the land ready earlier. On light land, plowing under a green crop in the spring generally gives the best results, while on heavy land fall plowing is often best. In the South the best rule is to turn under the green crop two weeks or a month before the next crop is to be planted. If the land washes and a winter crop can not be planted, it is better to leave the green crop on the ground than to leave the ground bare.

The turning under of this green matter also interrupts the capillarity of the soil, especially if the furrow slice is laid flat. In plow-

ing, therefore, the furrow slice should be laid slanting; an angle of 30° to 40° is recommended. (Fig. 12.) The soil should also be thoroughly rolled, so as to compact it about the mass of plant matter as much as possible. This will hasten decay and prevent the drying out of the soil. The compacting may be done best with a disk harrow, which will at the same time cut up the surface and prepare the seed bed. A corrugated roller is also an excellent tool. (Fig. 13.)

When the green crop is heavy it may be cut up by disking twice, the second time at right angles to the first, before plowing. A difficulty that may be encountered, however, is the piling up of the loose material in front of the plow. Some farmers have found it a good

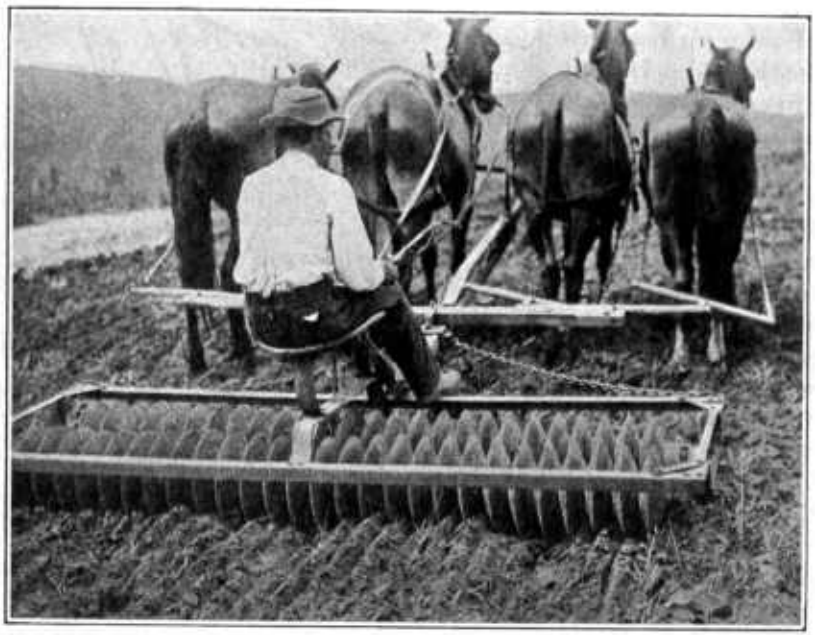

FIG. 13.—Packing the ground after turning under a green-manure crop.

plan to run a planker over the green-manure crop, so as to lay it flat in the direction the plow is to be run. A chain or a No. 9 wire may also be attached to the back of the plow beam and to one end of the whiffletree, so as to turn the mass into the furrow.

THE 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, 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, and their ability to choke out weeds.

When the whole crop is plowed under, the effect on the subsequent crops is determined mainly by three factors—namely, the quantity of humus formed, which is directly measured by the tonnage of the crop, 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 soils more rapidly than will nonlegumes. The effect of various legumes depends, however, not wholly on the nitrogen content, but is in an unknown way specific, as has been pointed out. 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 have on the succeeding crop or crops.

Green manures are of value in checking certain chlorotic diseases in orchards, and they are said to influence the quality of the fruit. How these effects are produced we do not know. In India the turning under of green manures just before planting the field to indigo is said to have made the plants more susceptible to insect attacks. From a practical standpoint, we know that green manures are generally beneficial, but we know very little about the processes through which this influence is exerted.

THE PRINCIPAL LEGUMINOUS GREEN-MANURE CROPS.

There are in the United States 14 leguminous field crops that are more or less extensively grown. In the approximate order of their importance these are: Red clover, alfalfa, alsike clover, sweet clover, cowpeas, peanuts, soy beans, velvet beans, crimson clover, field peas, vetch, Japan clover, bur clover, and white clover. A few more, such as beggarweed, grass peas, fenugreek, and horse beans, are cultivated to a less extent or in restricted localities. Many others are

being tested or have been tested in an experimental way, but as yet are not grown as crops.

From an agricultural point of view, legumes may be classified into three groups: (1) Summer annuals, including cowpeas, soy beans, peanuts, beans, velvet beans, and in the North common vetch and field peas; (2) winter annuals, comprising crimson clover, bur clover, hairy vetch, common vetch, and in mild climates field peas (in parts of the South red clover also behaves as a winter annual); and (3) biennials or perennials, embracing red clover, white clover, alsike clover, alfalfa, and sweet clover.

Each of these crops can be grown advantageously only in a more or less definitely limited region. For the particular purpose in view it rarely happens that a choice of two or more equally valuable legumes is offered. Usually one is so much superior to any other available legume that substitution is practically out of the question. In a few cases, however, the use of one legume in place of another is practicable. Thus, cowpeas and soy beans are agriculturally much alike and are adapted to nearly the same regions.

In like manner crimson clover, bur clover, and the vetches over a large area may be used one in place of another. In some sections the culture of red clover is no longer profitable, and alsike clover or sweet clover is being substituted. Alsike clover commonly yields less but will grow on soils deficient in lime. Sweet clover is even more dependent on the presence of lime in the soil than red clover, but when lime is supplied it will grow on poorer soil and resist more hardship than any similar crop. Being a biennial it can replace red clover in a rotation. It is one of the best soil-improving crops known. There is also an increasing use of alfalfa in place of red clover, but with alfalfa the best practice is to keep the fields in this crop three years or longer.

RED CLOVER.[1]

Red clover (fig. 8) is a biennial and the standard legume in farm rotations in the Northern States. It is commonly seeded with grain, cut for hay once and for seed if the conditions are right, and the aftermath pastured or turned under for the following crop. A very large proportion of the red clover seeded is put in with timothy. Mammoth clover, a large-growing form of red clover, is much used for soil improvement, as it makes a greater mass of growth than the medium red. Red clover is not infrequently seeded in wheat and either that fall or the following spring is turned under as a green manure for the next crop. At the Central Experimental Farm of Canada it was shown that the winterkilling of red clover did not de-

[1] *Trifolium pratense.* Consult Farmers' Bulletin 455, entitled "Red Clover."

stroy its fertilizing value. With the exception of its use as a catch crop the entire growth of red clover is probably seldom turned under for green manure, as it is too valuable for forage or for seed. The roots and stubble, however, contain much more fertilizing matter than is the case with most legumes. The roots of red clover extend to a depth of 4 to 6 feet, but much the largest portion is in the upper foot of soil. The proportion of root to top has been variously estimated. The Minnesota and Delaware Agricultural Experiment Stations found nearly half as many pounds of root as of top; the Wisconsin station one-quarter as much; the Central Experimental Farm at Ottawa more than two-thirds as much; while in 1-year-old clover in Michigan the weight of roots nearly equaled that of tops.

The percentage of the total fertilizer ingredients in the crop that is found in stubble and roots is also larger in red clover than in any other legume except alfalfa, though figures on sweet clover are not available. The Delaware Agricultural Experiment Station found that 30 per cent of the money value of the fertilizers in the crop was in the root. Red clover, therefore, is better suited than most legumes to a place in the rotation which requires the removal of the parts above ground and the use of the stubble and roots for keeping up the subsequent yields. However, it must not be thought that such a system can be continued indefinitely, except possibly on very rich soil. It has been found that on many soils turning under roots and stubble only once in three years is not enough to maintain yields.

CRIMSON CLOVER.[1]

Crimson clover (figs. 7 and 11) 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. On the Atlantic seaboard and in portions of the South it is the great winter cover and green-manure crop. While the root system is extensive, it does not compare favorably in this respect with red clover, the Delaware Agricultural Experiment Station finding but 10 per cent of the air-dry substance in the root, as against 30 per cent for red clover. However, the percentage of nitrogen in the entire plant is higher in crimson clover than in red clover. From Delaware to the Gulf of Mexico it is frequently seeded at the last working of the corn or cotton and turned under for the next crop. In the South it is necessary to turn it under before it has attained full development if it is to be followed by cotton, but if corn is to be planted the clover may be allowed to come into bloom, or a seed crop may even be taken and the stubble and straw turned under in time to plant late quick-maturing corn. In

[1] *Trifolium incarnatum.* Consult Farmers' Bulletin 1142, entitled "Growing Crimson Clover."

Delaware, where crimson clover is very largely used as a winter cover crop, it is thought that it should be plowed under at the first appearance of the blossoms, though some prefer to plow even earlier.

SWEET CLOVER.[3]

Sweet clover is a biennial and has but recently come into prominence as a forage crop and soil builder. In appearance, the plants when about half grown resemble alfalfa, though the leaves are larger and the plant has a bitter taste. When allowed to mature naturally, sweet clover makes a loose bushy plant, 5 feet or more high, with small white flowers in slender racemes. An important characteristic of this plant is the very large taproot, which is powerful enough to penetrate stiff clay soils and in which a great quantity of reserve food is stored up during the first season's growth. Yields as high as 30 tons of green fodder to the acre have been recorded, but there is yet no adequate record of the relation between roots and tops. The composition of sweet clover is nearly the same as alfalfa, showing that turning under a good stand of this crop would furnish a large quantity of fertilizer for the succeeding crop. Sweet clover is perhaps the most important green-manure crop in parts of Mississippi and Alabama. It also is used for this purpose in parts of Kentucky, Illinois, Iowa, eastern Kansas, and western Ohio.

Sweet clover will thrive on almost any soil provided it has plenty of lime. In this respect it has a wider range of usefulness than either red clover or alfalfa, doing well on soils too poor to produce a crop of either of these two plants. It thrives in all parts of the United States. North Dakota is not too cold nor is Alabama too hot, and it will get along with less water and more salt in the soil than any other cultivated legume. Both hulled and unhulled seed is used, and the hulled seed is often scarified. The use of the scarified seed is recommended, especially when prompt germination is wanted.

The seed bed for sweet clover needs to be very firm, and good stands have been obtained by seeding on land so hard that the drill would barely leave a mark. On land that has never grown sweet clover the seed should be inoculated. When grown in the South, soil on which bur clover has grown may be used for inoculation, as the same organism inhabits the nodules on the roots of sweet clover, alfalfa, and bur clover.

In 1916 an annual variety of *Melilotus alba*[4] was introduced to the public by Prof. H. D. Hughes, of Ames, Iowa. This variety grows rapidly, making a growth variously reported as from 3 to 6

[3] *Melilotus alba*. Consult Farmers' Bulletin 797, entitled "Sweet Clover: Growing the Crop."

[4] See U. S. Department of Agriculture Circular 169, entitled "Annual White Sweet Clover and Strains of the Biennial Form."

feet in height during one season. It forms no resting buds, and consequently does not live over winter. At present too little is known about the crop to permit a positive statement as to its value in the rotation. Many people are hopeful and some are enthusiastic regarding its future, but no data are at hand covering the various points that will affect the usefulness of this variety, except the fact that it makes its growth in one season and will under most conditions make more growth during the season of seeding than the biennial form.

The principal American crop rotations are built around biennial clover crops. Whether the annual variety will lend itself to good rotations remains to be learned. That the annual variety will prove useful may be confidently anticipated, but how useful as a green manure is a question that can not be answered at present.

YELLOW ANNUAL MELILOT, OR SOUR CLOVER.[5]

In the past few years sour clover has become one of the most extensively used green-manure crops in the citrus and walnut groves of southern California. Its extensive use was brought about by the experimental demonstration of its high fertilizing value together with the fact that the seed was available at a much lower price than the seed of any other legume that could there be used for green-manuring purposes. While the demand for this seed has greatly increased it still can be procured at a comparatively low figure. Most of the sour-clover seed on the market is obtained as a waste product from the grain fields of California and Arizona, where it occurs as a weed.

Sour clover is an annual. The requirements for its best development are about the same as for vetch and field peas, but it will not make as much growth during the average winter months in southern California as the other crops mentioned.

In California the minimum temperature at which it can make growth is higher than for common vetch, purple vetch, field peas, and some other plants, and partly for this reason it does not produce as heavy a growth for turning down early, by the middle of February in southern California for example, as do these other plants.

The fertilizing value of sour clover is high, and if a good growth for turning under at the proper time can be had its use is advisable.

BUR CLOVER.[6]

Without doubt one of the most valuable soil-improving crops for the cotton belt is bur clover. It is a winter annual but will not endure severe cold. In the Cotton States its value lies partly in the fact

[5] *Melilotus indica.*

[6] *Medicago rabica* and *M. hispida denticulata.* Consult Farmers' Bulletin 693, entitled "Bur Clover."

that it can be handled with a minimum of expense, reseeding itself readily and covering the ground during the winter, thus not only enriching the soil at a time when other crops can not be grown, but preventing washing and leaching. When used as a green-manure crop for the benefit of cotton or corn, rows of bur clover may be left standing at suitable intervals when plowing for the summer crop. The burs ripening on the plants thus left will reseed the field for the next winter's stand of bur clover.

There are two species in common cultivation, the Southern, or spotted, and the California, or toothed. Of these the Southern species seems best suited to the cotton belt, as it is a stronger grower and more resistant to cold. The seed of the Southern bur clover is commonly sold in the hull, and since particles of soil usually adhere to this, there is no need to inoculate. The California seed is hulled and does not carry inoculating germs.

ALFALFA.[1]

Alfalfa is grown as a cover and green-manure crop, particularly in the apple orchards of parts of Washington and Oregon and in the orange groves of the Salt River Valley of Arizona and to some extent in the irrigated apple orchards of Utah and Colorado. The use of this crop in orchards has become common only within the past few years, though it has been used by a few citrus growers in Arizona for about 20 years. In the Wenatchee, Wash., district about 75 per cent of the orchard area was planted to alfalfa in 1919.

The method of handling alfalfa in orchards is quite variable, though in all cases it is desirable to turn as much of the crop back into the soil as possible. In the Salt River Valley of Arizona good results have been obtained from orange groves in which the alfalfa was allowed to stand throughout the year, uncut and uncultivated. Cutting the crop at intervals and allowing it to lie without further attention also has proved satisfactory; also disking the crop into the soil. In Washington the crop is perhaps more often cut and disked into the soil, though removing the cut crop as hay is not uncommon. This latter practice, however, is not advised except when the need for immediate cash returns makes it necessary.

Alfalfa can be used successfully in orchards only when an adequate water supply is available. While it may save some water by preventing run-off and evaporation, it also uses a large quantity in its growth. Where an abundance of water is not available the alfalfa may use so much as to deprive the trees of what they need. Orchardists must also bear in mind that if a hay crop is taken the

[1] *Medicago sativa.* Consult Farmers' Bulletin 339, entitled "Alfalfa."

haying and spraying operations should be so managed as not to interfere with one another.

Alfalfa can not be used with equally good success in all orchard areas. Soils that are heavy usually require thorough cultivation and are not suited to a permanent crop. It is perhaps also true that a permanent cover crop can be used to much better advantage in regions having intense summer heat, though the exact relation of soil temperatures to crop production in this connection never has been definitely determined.

VETCHES.[8]

Two vetches in particular are cultivated in the United States, the common vetch,[9] or tares, and the hairy, or Russian,[10] vetch. The former is much used as a winter crop for hay and seed in western Oregon and Washington, being commonly sown alone or with oats or wheat. It is also extensively grown in the citrus orchards of California as a winter green-manure crop. In the Northern States it winterkills.

Hairy vetch is in a general way like common vetch, but decidedly more resistant to cold. It will ordinarily survive the winter in most parts of the United States and in Canada. In fact, it is more resistant to cold than any other annual legume grown. On this account it is particularly valuable in the North. Where the winter temperature is not cool enough to prevent growing, as in California, it has been found that hairy vetch grows much more slowly in cool weather than the common vetch, and the latter is therefore preferred. Hairy vetch, however, grows very rapidly as the weather becomes warm.

Hairy vetch is especially used in Michigan both as an orchard cover crop and for the improvement of sandy land. It has been found more successful on the light lands of western Michigan than any other legume that can be seeded in late summer.

Purple vetch[11] is a new and very promising crop for green manure. It is especially adapted for use in the citrus orchards of the southwestern United States. Under mild winter conditions, such as prevail in that region, it makes more winter growth than either common or hairy vetch. It is less winter hardy than common vetch and can not be grown successfully as a winter annual in regions where the winter temperature falls much lower than 15° F. above zero.

Hairy vetch is objectionable where small grains are used in rotation, as it becomes somewhat weedy in grain fields. Common vetch volunteers to some extent. Except for this, vetches are very valuable crops and deserve much more extensive cultivation.

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[8] Consult Farmers' Bulletin 515, entitled "Vetches."

[9] *Vicia sativa.*

[10] *Vicia villosa.*

[11] *Vicia atropurpurea.*

THE COWPEA.[12]

In the South the cowpea (see title-page) is used more than any other crop as a soil enricher. It is characterized by remarkable ability to grow in poor soils and to cover the ground so densely as to choke out most weeds. It usually bears on its roots an abundance of nodules, whether the soil has been inoculated or not, although in localities where the cowpea has not been grown previously the nodules may be absent. In such cases inoculation becomes necessary, for it is through the nodules on the roots that the beneficial effects of the cowpea are produced.



FIG. 14.—Soy beans in cultivated rows, showing the upright habit of the plants.

Cowpeas are commonly planted between rows of corn at the time of the last cultivation, or they are broadcasted upon the stubble of small grains and disked in. Cowpeas, however, like other crops, respond markedly to cultivation, and there is a growing tendency to plant them upon well-prepared soil. This practice results in a great increase of the crop, whether grown for hay or for seed.

More numerous experiments have been conducted in this country to determine the effects of cowpeas used as a green manure than have been devoted to all other leguminous crops combined. Almost without exception these experiments have indicated a very beneficial effect upon subsequent crops. The benefit often lasts two or three years. These good results appear with practically all

[12] *Vigna sinensis.* Consult Farmers' Bulletins 1148 and 1153, entitled, respectively, "Cowpeas: Culture and Varieties" and "Cowpeas: Utilization."

crops—cotton, corn, sorghum, or small grains. Except on the poorest soils, careful experiments show that it is decidedly more profitable to use the cowpea crop as hay or pasture and then plow under the stubble than it is to plow under the whole crop. Although plowing under the whole crop produces, as a rule, a greater effect, it is not enough greater to equal the value of the crop as feed.

SOY BEANS.[13]

Soy beans are adapted to a much wider range of climate than cowpeas, being grown successfully even in Ontario and Wisconsin. As a forage crop, soy beans have some points of superiority over cowpeas, the hay being rich in protein and somewhat easier to cure. The seed is cheaper than that of cowpeas, usually costing only two-thirds as much, principally because of the fact that the seed can be harvested by machinery. It also has the advantage that the seeds are but little affected by weevils and that the plant is not subject to wilt. On these accounts soy beans are preferred by an increasing number of farmers in the South. Soy beans, however, are not able to compete with weeds as successfully as cowpeas, and on this account the best results are obtained by planting in rows so that they may be cultivated (fig. 14). Considerable difficulty is experienced at first in obtaining nodules on the roots of soy beans, but when once these have appeared there is no further trouble with that particular piece of ground. Apparently, soy beans have a greater power than cowpeas to absorb atmospheric nitrogen through their roots (see fig. 1).

VELVET BEAN.[14]

The velvet bean is somewhat objectionable for green manuring on account of the very viny habit of the plant, which renders it difficult to plow under (fig. 15). In orchards velvet beans have been found undesirable on account of their tendency to climb the trees, but the new bush velvet bean overcomes this objection. At the Arkansas Agricultural Experiment Station velvet beans gave better results on a subsequent crop of cotton than either soy beans or cowpeas. With wheat, velvet-bean stubble gave better results than either cowpea stubble or soy-bean stubble, though the difference was very slight. It is noteworthy also that velvet-bean stubble gave much better results on the succeeding crop of wheat than where the whole crop of velvet-bean vines was plowed under, and the same was true in regard to both cowpeas and soy beans. In all cases, however, there was a marked increase of crop, due to the influence of legumes. Velvet

[13] *Soja max.* Consult Farmers' Bulletin 973, entitled "The Soy Bean: Its Culture and Uses."

[14] *Stizolobium deeringianum.* Consult Farmers' Bulletin 962, entitled "Velvet Beans."

beans can not be grown so far North as cowpeas, and not nearly so far as soy beans.

MISCELLANEOUS LEGUMES.

Of less importance than the crops described but yet of considerable use under special conditions is the field pea.[15] This pea was once considerably used in California as a winter green-manure crop in orchards, but it has lately been replaced by other crops. At present, peas are used as a green-manure crop in the orchards about San Antonio, Tex.

The Tangier pea,[16] a native of North Africa, resembles in a general way the garden sweet pea. It has given the largest yields of



FIG. 15.—A crop of velvet beans 3 months old, showing a great mass of material for soil building.

green matter to the acre of any annual legume grown in California. The dense growth chokes out weeds completely. It is a good green-manure crop, but the seed has been hard to get. There is hope that this difficulty may be overcome.

The upright-growing horse bean produces[17] a great deal of green matter in some sections, but it is not generally equal to vetch. Lupines and yellow trefoil are used very much in Europe but not in America. Fenugreek has done well in California, especially in sections near the coast. Wild hemp[18] is used to a small extent as a

[15] *Pisum sativum.*
[16] *Lathyrus tingitanus.*
[17] *Vicia faba.*
[18] *Sesbania macrocarpa.*

green manure on irrigated lands in Arizona and southern California; the partridge pea [19] grows wild on sandy land in the eastern United States and has been used for soil improvement in Maryland. Its use is at present spreading in parts of southeastern New Jersey.

NONLEGUMINOUS GREEN-MANURE CROPS.

CRUCIFERS.

Cruciferous plants (of the mustard family) are seldom grown in the United States for green manure, though rape is not uncommonly used for hog and sheep pasture. In England, however, both rape [20] and white mustard [21] are frequently used for turning under, and under certain circumstances give better results than a leguminous crop. Reports for a number of years from the Woburn Station showed that yields of wheat were better after green manuring with rape and mustard than after vetches. The soil of the vetch plats, however, contained more moisture, organic matter, and nitrogen than the soil on the rape and mustard plats. In Germany also mustard has been very successfully used as a green manure.

The use of rape and of cowhorn turnips for orchard cover crops has been strongly recommended by some New York and New England authorities. It is possible that on some soils in this country the seeding of rape or turnips on grain stubble to be grazed or turned under for winter grain may prove advantageous.

GRASSES AND OTHER CROPS.

Aside from the turning under of sod, the only grass or grain crops that are used as green manure are small grains, such as rye, wheat, barley, oats, and millet. Of course, any young grain or grass crop could be turned under if circumstances warranted, but as a matter of fact rye and sometimes in the East wheat and barley are about the only grain crops that are used in this way.

Rye is perhaps more commonly used than any other grass or grain as a winter cover and green-manure crop. It is adapted to fall sowing over a wide extent of territory, is extremely hardy, and will make a heavy growth early enough in spring to be turned under for any spring crop. Rye will not add nitrogen to the soil except as the decaying organic matter may furnish carbon as food for the organisms which fix atmospheric nitrogen. It will, however, furnish large quantities of organic matter, absorb a portion of the soil nitrates, and tend to prevent the loss of nitrogen by leaching during winter.

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[19] *Cassia chamaecrista.*

[20] *Brassica napus.*

[21] *Brassica alba.*

In a 6-year test on the availability of different forms of phosphorus the Maryland Agricultural Experiment Station recorded better results from plats on which rye had been used as green manure than on those on which crimson clover had been grown. The prevailing experience has been, however, that where a legume can be grown the results are better than those secured from turning under rye.

Millet is used only as a summer catch crop and is rarely turned under. So far as recorded evidence goes it is not desirable as a green-manure crop.

BUCKWHEAT.

Buckwheat is often grown on poor soil in the North and turned under. It will make some growth on very poor soils, on which clovers would not thrive at all. Buckwheat ranks high in the quantity of fertilizer constituents per 1,000 pounds of green matter, outranking in this respect even alfalfa and clover; but, of course, all the nitrogen in the buckwheat is taken from the stores in the soil, and by turning the crop under the soil becomes richer only in organic matter and in the greater availability of the mineral fertilizers. Buckwheat has long been noted for the excellent effect it has on the texture of the soil. A mixture of buckwheat and peas is said to make a good orchard cover crop in New York. The heavy growth is rolled flat at apple-picking time and makes a desirable floor cover. In the peach orchards of Michigan, on sandy soil, bad results are reported to have followed the use of buckwheat, the leaves of the peach trees turning yellow or reddish yellow and curling. How far this result may be expected on other types of soil is not known, but buckwheat as a cover for peach orchards should be used with caution.

WEEDS.

The so-called "Mexican clover"[22] is not a clover and does not belong to the legume family but to the madder family, to which coffee belongs. It has been introduced into the Gulf coast section from Central America and grows spontaneously as a weed. On sandy land it is used as a green manure and serves the purpose of supplying organic matter, but without directly making the soil richer in nitrogen.

Other weeds also often serve as green-manure plants and are sometimes encouraged to grow for that purpose. Many prominent orchardists do not sow a green-manure crop but allow the weeds to grow in late summer and believe that a heavy crop of weeds makes an effective cover crop. In this case the weeds hardly serve as green

[22] *Richardsonia scabra.*

manure, however, since they do not survive the winter, and only such dried parts as remain in the spring are turned under. In California various weeds, including alfilaria,[23] or "filaree," bur clover, and various annual grasses, are regularly counted on in the Sacramento and San Joaquin Valleys to make volunteer green-manure crops in deciduous orchards.

In the Connecticut tobacco section the growth of chickweed[24] is encouraged in order that it may be turned under for green manure. The soil being well fertilized for the tobacco crop, the chickweed makes a heavy growth in the fall. The lower portions of the plants remain alive, and the crop is allowed to seed before the land is plowed for tobacco the next season. In parts of central Tennessee the wheat farmers encourage the growth of ragweed and smartweed and turn the stand under after the plants have produced seed. It is possible that a better practice might be followed, but the mid-summer drought in this section is usually too severe to permit the seeding of any crop after wheat harvest. The weeds in this case do help somewhat in adding organic matter to the soil.

[23] *Erodium* sp.

[24] *Stellaria media.*

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

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