SOME EFFECTS OF LEGUMES IN RELATION TO ECONOMICAL CROP PRODUCTION

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SOME EFFECTS OF LEGUMES IN RELATION TO ECONOMICAL CROP PRODUCTION

R. C. COLLISON

ABSTRACT

Some important effects of legumes as indicated by the lysimeter investigations of this Station are presented here and their relation to economical crop production discussed.

The importance of the rooting habits of legumes on soil, plant growth, and the interchange of plant food materials and water utilization is indicated.

The nitrogen relations of legumes and non-legumes are described from the standpoint of (a) their nitrogen content as affecting the growth of the crops which follow them; (b) crop yields after legumes and non-legumes; (c) nitrogen removal in crops and nitrogen loss in legume and non-legume rotations; and (d) fertilizer economics of legume rotations.

The proportion and distribution in the soil of the root system of legumes is a factor often overlooked in appraising their value to agriculture.

The nitrogen content of the alfalfa plant was found to be some $2\frac{1}{2}$ times as great as that of timothy, which has an important bearing on the growth of the crops which follow them. This may show itself by a stimulation of crop growth due to a high nitrogen level after a legume, such as alfalfa, and a depressing effect on the crop which follows such a crop as timothy.

In the lysimeters the increase in yields of barley immediately following alfalfa has amounted to as much as 43 bushels over that following timothy.

The greatest increase in crops following alfalfa and the most marked yield depression in crops following timothy appear the first year after the alfalfa and timothy are spaded under. By the second year both effects have greatly declined.

In spite of the fact that 3 times as much nitrogen has been removed by crops in the alfalfa rotation as in a timothy rotation, nevertheless in the former rotation, on the poorer soil, $2\frac{1}{2}$ times as much nitrogen has been lost in the drainage water.

The great importance of utilizing this store of available nitrogen economically is pointed out.
Alfalfa in these experiments has used water as economically as timothy and in the field has the property of tapping the deeper supplies of moisture beyond the reach of many other crops.

The high soil nitrogen level in legume rotations has resulted in a higher protein content of the grain crops following the legume.

After alfalfa had been established on the poorer soil the crop yields and nitrogen relations have compared quite favorably with those of the productive Ontario soil. The nitrogen and organic matter produced by the alfalfa crop has been peculiarly beneficial to the poorer soil.

INTRODUCTION

In the present economic depression which involves agriculture as well as all other industries, an exhaustive search for effective methods of alleviation is highly commendable. At the same time however, it is well to keep in mind the fundamental factors which always make for economical production, since cost of production is an important consideration in the present situation. Many factors contribute to the cost of producing farm crops, but this publication calls attention to only one, altho a very fundamental one, namely, the importance of legumes in comparison with non-legumes in their effects on crop yields, fertilizer economics, moisture relations, and general soil conditions.

SOURCE OF DATA

Most of the following statements and conclusions are based on the lysimeter investigations of this Station which have been carried on for the past 16 years. In these experiments complete intake and loss of nutrient materials have been determined in two rotations on two types of soil. The first rotation consists of alfalfa for two years followed by barley and then by wheat. The second rotation consists of timothy for two years, followed by the same grain crops. One soil is an infertile, rather heavy loam, lacking in lime, and is more or less typical of much of the hill land of southern New York. The other soil is an Ontario loam well supplied with lime and quite productive. If further information concerning the lysimeter investigations is desired, it will be found in Technical Bulletin No. 166 and future publications on the lysimeter work of this Station.

THE IMPORTANCE OF LEGUMES

It is not the intention here to point out the many reasons for growing legumes in an economical system of soil maintenance, but rather to call attention to several phases of legume growth not
commonly stressed, and also to present some new data from the lysimeter work bearing on the subject of water, nitrogen, and crop yield relations of legume and non-legume rotations.

THE IMPORTANCE OF ROOTS

Since the roots of plants are ordinarily hidden from view, their great importance is usually overlooked or entirely neglected. As much as one-third or more of the total weight of a plant may lie below the soil surface. Plants vary enormously in this proportion, but it is extremely important, since roots are very valuable both to the fruit grower and to the grower of agricultural crops. Roots contain plant food elements which they leave in the soil. They also absorb a part of such nutrients from the lower depths of the soil and leave part of them in the upper depths and *vice versa*. Furthermore, the roots make channels for drainage which may be of value in soils having impervious subsoils. They also add to the organic matter and humus in the lower soil depths. One of the greatest values of plant roots is the mechanical condition in which they leave a soil. This has a marked bearing on the ease of soil operations and the growth of the succeeding crop. Then, the most effective distribution of organic matter in a soil is thru the growth of plant roots. Roots permeate every part of a soil, in fact it would probably be impossible to mix the same amount of organic matter mechanically in the form of manure in anything like the degree to which the roots of plants effect this mixing. This intimate mixing affects both the soil structure and the ease with which soil organisms can bring about the many biological changes which are necessary before fresh organic matter becomes an intimate part of a soil.

Plants not only vary enormously in the proportion of the total plant which may lie below the surface of the soil at any particular stage of growth, but they also vary in the type and extent of the roots, horizontally and vertically, in the soil. Altho data on these points are meager, the following figures, gathered from a number of sources, bring out several important considerations: In the rye plant it has been found that only about 5 per cent of the total plant is in the roots, for wheat this figure is 8½ per cent, barley 8½ per cent, oats 10 per cent, peas 6 per cent, soybeans 12 per cent, vetch 17 per cent, sweet clover 26½ per cent, and red clover and alfalfa 33½ per cent.

Herein lies one of the special values of legume plants, especially the biennial and perennial legumes. The roots of the cereals may be comparatively unimportant as regards this proportion, while such
legumes as red clover and alfalfa may carry as much as one-third their total weight in their roots.

These figures, however, do not tell the whole story since the vertical distribution of roots is also very important. The figures given in Table 1, also gathered from several sources, give an idea of the comparative value of the legumes and non-legumes in this respect.

**Table 1.—Root Distribution of Some Legumes and Non-Legumes.**

<table>
<thead>
<tr>
<th>Depth, inches</th>
<th>Wheat</th>
<th>Barley</th>
<th>Oats</th>
<th>Alfalfa</th>
<th>Red clover</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>55.0</td>
<td>61.2</td>
<td>67.7</td>
<td>6.6</td>
<td>15.7</td>
</tr>
<tr>
<td>10-20</td>
<td>17.4</td>
<td>18.0</td>
<td>10.7</td>
<td>8.5</td>
<td>44.8</td>
</tr>
<tr>
<td>20-30</td>
<td>14.8</td>
<td>10.7</td>
<td>13.9</td>
<td>14.0</td>
<td>24.2</td>
</tr>
<tr>
<td>30-40</td>
<td>6.0</td>
<td>8.4</td>
<td>6.3</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>40-50</td>
<td>6.5</td>
<td>1.5</td>
<td>0.6</td>
<td>32.3</td>
<td>3.7</td>
</tr>
</tbody>
</table>

If these figures approximate the truth, it will be seen that the cereals have over one-half their total root systems in the first 10 inches of soil and practically all their roots in the first 30 inches. Alfalfa and red clover, on the other hand, are deep feeders, the former having 44 per cent of its root system below 30 inches and red clover 15 per cent below this depth. Both of these legumes have comparatively small proportions of roots in the first 10 inches.

This factor of amount and distribution of roots is an important one to consider in selecting cover crops for orchards and legume crops for ordinary rotations. If, as some experiments indicate, phosphorus and potassium when applied as commercial fertilizers are absorbed and retained by the surface layers of soil and are thus prevented from reaching tree roots, deep-rooting legumes may take some of these elements from the surface to the lower root zones of the tree.

**THE NITROGEN OF LEGUMES AND NON-LEGUMES**

The property which is usually thought of in connection with legumes is their ability to fix free atmospheric nitrogen. This is commonly thought to be the main value of legumes from a crop rotation standpoint. The other common consideration is the feeding value of legumes which depends mainly on their nitrogen or protein content.

This nitrogen content, however, has another important aspect, especially when compared with the nitrogen content of some of the
non-legume plants. This variation in nitrogen content in the crops grown on the lysimeters is given in Table 2.

**Table 2.—Percentage of Nitrogen in Crops on Lysimeters.**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Hill soil</th>
<th>Ontario soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa-grain rotation</td>
<td>Timothy-grain rotation</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>3.15</td>
<td>___</td>
</tr>
<tr>
<td>Timothy</td>
<td>___</td>
<td>1.16</td>
</tr>
<tr>
<td>Barley grain</td>
<td>2.43</td>
<td>2.13</td>
</tr>
<tr>
<td>Barley straw</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>2.28</td>
<td>2.09</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>0.55</td>
<td>0.41</td>
</tr>
</tbody>
</table>

It will be noted that alfalfa carries over 2½ times as much nitrogen as timothy. This fact has an important bearing on the effect of these two crops on the crop which follow them. It has been found that crops or crop residues which have a low nitrogen and a high carbon content, when incorporated with soil, do not furnish enough nitrogen to supply the soil organisms which decompose the crops. In using the carbon of such crops these organisms have to have more nitrogen, so they take it from the soil and thus compete with growing plants. This may result in a depressing effect on the growth of plants which follow such crops or residues, and if the soil is already low in available nitrogen there may be no nitrogen for plant growth for several months after these low-nitrogen crops are plowed in. The bad effect of plowing under quantities of straw or very strawy manure is explained in this way, also probably the injurious effect of rye on peach trees which is sometimes noted.

On the other hand, the legume crops which contain much more nitrogen, or in other words, in which the ratio of nitrogen to carbon is much narrower, do not have this effect because they contain sufficient nitrogen to supply soil organisms and thus rot down in a comparatively short time. This further results in the nitrogen of legume crops becoming available to growing plants much more quickly.

These two effects of legumes, namely, their distinctive root habits and the effects of their nitrogen content, are quite distinct from their well-known nitrogen-fixing ability and may be overlooked in appraising their comparative value to agriculture. Both of these effects have been especially noted in the lysimeter work used as a
basis of this publication. The effects of alfalfa as compared with that of timothy or the cereals on soil tilth have been marked. To what extent the marked effects of legumes on the grain crop following, as given in Table 2, can be ascribed to these two properties and to what extent to their nitrogen-fixing property it is impossible to say, but it is believed that both these factors have been very important. It is also believed that the data indicate that the depressing effect of timothy residues has had considerable influence on the yields and composition of the grain crop following.

EFFECT OF A LEGUME AND A NON-LEGUME ON YIELD OF CROPS WHICH FOLLOW

The data on the yields of crops in the alfalfa-grain and timothy-grain rotations are presented in Table 3. The figures given are pounds of dry matter per acre for six crops of alfalfa and three crops each of barley and wheat. (See also Figs. 1 to 6.)

Fig. 1.—Barley Following Alfalfa on Hill Soil, no Nitrogen Applied.
Table 3.—Crop Yields After Alfalfa and Timothy.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Hill soil</th>
<th>Ontario soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa-grain rotation</td>
<td>Timothy-grain rotation</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>40,956</td>
<td>21,203</td>
</tr>
<tr>
<td>Timothy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley grain</td>
<td>9,905</td>
<td>3,713</td>
</tr>
<tr>
<td>Barley straw</td>
<td>10,531</td>
<td>4,242</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>6,714</td>
<td>5,205</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>12,826</td>
<td>11,772</td>
</tr>
</tbody>
</table>

From these results it will be noted that on the less fertile soil alfalfa has produced some 3,276 pounds more dry matter per acre annually than has timothy, and of course of higher feeding value. This excess on the better soil is 2,178 pounds dry matter per acre per year. Barley grain has yielded after alfalfa 43 bushels more per acre annually than after timothy and this on a dry-matter basis. This is a
very large difference and probably much greater than could be expected under field conditions. This excess in favor of alfalfa on the better soil has amounted to 41½ bushels, also on a dry-matter basis.

When the yields for wheat, which follows the barley, are compared, it is noted that here the differences are not nearly so great. In the alfalfa rotation wheat has yielded, for the poorer soil, about 8½ bushels more per acre annually than in the timothy rotation and for the better soil 6 bushels more. The relative differences for barley, which immediately follows the alfalfa and timothy, and the wheat crop, which is two years removed from these crops, indicate that probably two things are happening to reduce the differences in yield for wheat. First, the crop which immediately follows alfalfa gets the greatest benefit from its residues, both in its accumulated nitrogen and its favorable effect on the physical condition of the soil. On the other hand, the crop immediately following timothy received the principal effect of the deleterious action of this crop in locking up soil nitrogen. Both the good effects of alfalfa and the
temporarily injurious effects of timothy largely decrease the second year after their incorporation in the soil so that the yields of wheat in the two rotations show much smaller differences.

This same thing is also very strikingly brought out in Tables 4 and 5 which give the amount of nitrogen removed in crops and in drainage water from the alfalfa and timothy rotations.

In Table 4 it will be noted that the total nitrogen removed by crops from these soils is very large, amounting in its maximum to 2,087.2 pounds per acre for the 12 years. This amount is equivalent to over 614 tons of nitrate of soda per acre for the period, or well over 1,000 pounds per acre per year removed by crops in an alfalfa-grain rotation on a good soil. It will be further noted that on the poorer soil there has been removed from the soil in crops in the legume rotation an excess of 110 pounds of nitrogen per acre per year, equivalent to 687 pounds of nitrate of soda, over the amount removed in the timothy rotation. For the better soil this excess is almost as large, namely, 104.3 pounds, equivalent to 652 pounds of nitrate of soda per acre per year.
Table 4.—Nitrogen in Pounds per Acre Removed by Crops in Legume and Non-legume Rotations, Total for 12 Years.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Hill soil</th>
<th>Ontario soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa-grain rotation</td>
<td>Timothy-grain rotation</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>1,284.6</td>
<td>—</td>
</tr>
<tr>
<td>Barley</td>
<td>328.7</td>
<td>116.2</td>
</tr>
<tr>
<td>Wheat</td>
<td>218.0</td>
<td>153.6</td>
</tr>
<tr>
<td>Timothy</td>
<td>—</td>
<td>241.8</td>
</tr>
<tr>
<td>Total</td>
<td>1,831.3</td>
<td>511.6</td>
</tr>
</tbody>
</table>

Fig. 5.—Barley Following Clover on Productive Soil, no Nitrogen Applied.

In the face of these figures it might seem logical to assume that with almost 3 times as much nitrogen removed in crops from an alfalfa-grain rotation as from a timothy-grain rotation, less nitrogen would appear as excess in the drainage from the legume rotation. Such is not the case, however, as is shown in Table 5. On the poorer soil during the 12-year period, the alfalfa-grain rotation has shown an excess of 171 pounds of nitrogen lost in the drainage water over
<table>
<thead>
<tr>
<th>Crop</th>
<th>Hill Soil</th>
<th>Ontario soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alfalfa-grain rotation</td>
<td>Timothy-grain rotation</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>23.8</td>
<td>—</td>
</tr>
<tr>
<td>Barley</td>
<td>144.2</td>
<td>65.4</td>
</tr>
<tr>
<td>Wheat</td>
<td>122.5</td>
<td>44.5</td>
</tr>
<tr>
<td>Timothy</td>
<td>—</td>
<td>9.9</td>
</tr>
<tr>
<td>Total</td>
<td>290.5</td>
<td>119.8</td>
</tr>
</tbody>
</table>

**Fig. 6.—Barley Following Alfalfa on Hill Soil, Alfalfa Fertilized with Nitrogen.**

that lost from the timothy-grain rotation, an amount equivalent to 1,067 pounds of nitrate of soda. This excess for the better soil is 32 pounds, equivalent to 200 pounds of nitrate of soda. The table further shows that by far the largest part of this excess has been lost while the soil was growing the grain crops. This fact indicates that alfalfa is quite effective in utilizing the nitrate produced during its own growth.
FERILIZER AND CROP ECONOMICS OF LEGUME AND NON-LEGUME ROTATIONS

With the foregoing figures in mind it is well to consider the economical aspect of the results. None of the crops which have been discussed up to this point received a pound of additional nitrogen in commercial fertilizers. However, they all received a liberal application of phosphorus and potassium. As a matter of fact a similar alfalfa-grain rotation on the poorer soil did receive additional nitrogen in the form of 700 pounds of dried blood applied in most cases to the alfalfa. The crop yields of this rotation are given in the third column in Table 3. It will be seen that the crop yield increases over the same rotation without applied nitrogen are rather small. It has been found, however, that the loss of nitrogen in drainage water with applied nitrogen has been quite large, indicating that alfalfa has apparently supplied about all the nitrogen necessary for high production while any excess appears in the drainage water.

It is extremely important to utilize the large supply of nitrogen made available by the growth of legumes. If no crop of any kind occupies the soil after the legumes, the losses of nitrogen may be very great. Such losses might occur for example if legumes used as orchard cover crops were early fall plowed and no crop sown until the following spring. The magnitude of these losses is also given by data from the lysimeters. In a rotation on the poorer soil, alfalfa was grown for two years then spaded under and the soil fallowed for two years. The soil in this rotation lost nitrogen in the drainage water equivalent to 6,444 pounds nitrate of soda per acre for the 12 years, or 537 pounds a year. This amount was lost completely so far as crop utilization was concerned.

It is essential, therefore, not only to have a crop occupy the land after legumes especially, but also from the economical standpoint to choose a crop which will make the best use of the nitrogen. A heavy feeding crop or one of high money value would be preferable, such as corn, cabbage, or potatoes or some of the truck crops grown under field conditions. It should be remembered also that legumes contain large amounts of other food elements, such as phosphorus, potassium, and lime, which are readily available to other plants when the legumes decompose.

OTHER IMPORTANT EFFECTS OF LEGUMES

In this same lysimeter work a study was made of water utilization by the various crops. It was found that alfalfa produces its dry substance with no more or even less water than does timothy.
Furthermore, the much larger proportion of the roots of legumes in the lower soil depths has already been noted. This means that the legumes have the power to tap subsoil moisture which has moved downward and is beyond the reach of shallower rooted non-legumes. In other words, the legumes are able to tap a lower soil moisture level than most plants. Furthermore, it was found that the other crops in the alfalfa-grain rotation were produced per pound of dry substance with less water than the same crop in the timothy-grain rotation. This is undoubtedly due to the better supply of soil nitrogen in the legume rotation, since it has also been shown that abundance of nitrogen reduces water utilization by a crop. This factor is important in times of deficient moisture.

Again, the nitrogen content, and consequently the protein content, has been a little higher in the grains grown in the legume rotation than in those of the timothy rotation, as may be noted from Table 2. This effect is more marked for the poorer soil, where the difference amounts to almost 2 per cent protein for barley grain and over 1 per cent for wheat grain. It is not known if the nitrogen content of the grain crops would have been increased had the timothy crop or the grain crops themselves been given additional nitrogen. They probably would have been.

**EFFECTS ON THE SOIL ITSELF**

As has already been noted two quite different types of soil were used in these studies. As has also been noted, the hill soil, probably a Lordstown loam, with other similar types, occupies a large part of the hill lands of New York's southern tier of counties and extends well up into the tier to the north. The particular soil which was used in these studies came from near Burdette in Schuyler County, altho similar soil occurs in this section of the State as far north as southern Ontario County.

These soils are characterized by rather high clay or silt content, a deficiency of lime, and readily decomposable organic matter and in many cases rather poor drainage. Some of them are high in sandstone and shale fragments. Many so-called abandoned farms occur on some of these soil types. Strangely enough many of these soils compare well with some of our most productive soils in total nitrogen content, but this nitrogen is apparently not readily available to plants so that perhaps one of their outstanding needs is for easily decomposable organic matter. This characteristic of these soils was noted some years ago in a study which this Station made of the soils
of the Chautauqua County Grape Belt. In fact this fruit crop is quite extensively grown on these soils. Some years ago also this Station endeavored for several years to grow both alfalfa and sweet clover on many of these poorer soil types in most of the southern counties of the State. It was found that by thoro cultivation by summer fallowing to secure a good seedbed and by the use of large applications of lime and phosphorus alfalfa could be started successfully and in some cases would maintain itself for several years, but in many other cases the seeding would not survive the winter.

Therefore, when this type of soil was placed in the lysimeter tanks in the studies reported here, it was with some misgiving as to the degree of success which would be attained in growing a rotation with alfalfa as the legume. Adequate liming, cultivation, and drainage, however, have made success with this crop especially marked. Furthermore, the effects of this legume on the soil and on the other crops of the rotation are especially significant. The general crop yields have compared quite favorably with those on the fertile Ontario loam, while the differences in yields between the crops in the legume and non-legume rotations have been considerably greater on this poorer soil, as will be readily noted in Table 3. More nitrogen has appeared in the drainage from the legume rotation on hill soil than from Ontario soil. Furthermore, on the hill soil the amount of nitrogen removed in crops during the 12 years from legume rotations compares well with that from the better soil, while the difference in amount removed in the contrasted rotations is greater for hill soil. The nitrogen content of alfalfa, barley, and wheat is as much or more when grown on hill soil.

These facts indicate that alfalfa has been peculiarly beneficial on this unproductive type of soil. This effect has been so marked that the increase in nitrogen alone due to the legume does not seem to account for it entirely. Probably the incorporation of the easily decomposable organic matter in the alfalfa has had important effects on soil tilth, aeration, and biological and chemical changes in soil constituents which have been particularly beneficial to this soil.

If these soils are to be improved now or at some future time or if extensive areas now practically abandoned are to be brought back under cultivation, the growing of alfalfa, sweet clover, or some legume more easily established on such soils would be especially beneficial.