1925

An ecological study of pasture cover

Marshall Olin Lanphear

University of Massachusetts Amherst

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An Ecological Study of Pasture Cover

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AN ECOLOGICAL STUDY OF PASTURE COVER.

by

Marshall Olin Lamphere

Thesis submitted for the degree of Master of Science
Massachusetts Agricultural College
Amherst, Mass.
1926
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A. INTRODUCTION.

According to the report of the Land Utilization Committee (18) appointed by the Secretary of Agriculture in 1921 there are approximately 231,000,000 acres of humid grassland pasture in the United States. This area has an average carrying capacity of about one animal unit per five acres. (An animal unit may be defined as the equivalent of a mature horse, cow or steer, five hogs, or seven sheep.) In addition to the above it is estimated that there are 587,000,000 acres of arid and semi-arid pasture and range, practically all of which is located in the West. The productiveness of this area is low, however, about twenty-four acres being required for one animal unit. Considering the potential acreage of agricultural land in the United States as 1,734,000,000 acres (18), it thus becomes apparent that nearly one half of that area is now devoted to pasturage.

Hand in hand with our rapid development in population has come a rather constant expansion of our acreage in cultivated crops. In the earlier decades this increase was at the expense of our forest areas. Recently, however, it has come from the pasture land. The rapid increase in crop acreage during the world war was largely from this source. The result is that our grazing area is gradually being pushed back upon the non-tillable land of low productiveness. But here another competitor appears - forests. To quote from the report of the Land Utilization Committee (18) - "at the present rate of per capita consumption and waste and rate of growth in our growing forests 1,465,000,000 acres will be required to meet the timber needs of a population of 150,000,000." This is their population estimate for 1950. Such an acreage is impossible,
of course. Due to the conflicting interests of food and timber it is probable that a marked reduction will be made in our forest area along with economies in consumption. The forest service (19) prophesies an acreage of about 500,000,000 to maintain reasonable standards of living indefinitely.

Scientific forestry will not alter the problem greatly, however. Population will continue to increase. With this increase and the subsequent demand for more arable land, pastures will be pushed farther and farther back upon the rougher, more stony or infertile soils which are unsuited for crop production. There they will come in competition with forests which will lay a just claim to the poorer areas. Caught between two fires our pastures, and consequently our meat and milk diet, must suffer unless we can find some way of increasing the efficiency or carrying capacity of our grazing lands.

The situation appears all the more aggravated when we consider that not only is our potential pasture area diminishing rapidly but also the carrying capacity of each acre. K. E. Barnes (3), reporting for southeastern Ohio, states that since 1870 there has been a decrease of 33 per cent in the number of livestock units which land pastured continuously for fifty to one hundred years can carry. This checks with reports from other investigators.
In Massachusetts, as in other glaciated states, there are large areas of soil which would be classified as the stony loams and fine sandy loams of the glacial till series - especially the Gloucester. Due to a preponderance of stone or a rather undesirable topography, such land cannot be profitably utilized for cultivated crops. On the other hand, it does not seem economical to devote these areas to forestry which could be well developed on the light, infertile, droughty, outwash plains or on the rough, stony land, both of which soils we have in abundance. If we must have pastures, it seems logical that these stony loams and fine sandy loams be reserved for that purpose, especially in view of the fact that the texture of these soils fits them admirably for pasture grasses.

It must be borne in mind, however, that these soil types are of such a nature that they can never be worked with ordinary tillage tools. If they are to be pasture, they must be permanent pasture. They cannot be improved by cultivation. Unfortunately, such areas show a marked tendency to run out to worthless weeds. A typical field presents a plant community of hairy cap moss (Polytrichum commune), running cinquefoil (Potentilla canadensis), dewberry (Rubus villosus) and often, in addition, a shrubby growth of hardhack (Spiraea tomentosa). Where one acre of good white clover (Trifolium repens) and blue grass (Poa pratensis) should pasture a cow throughout an average summer, such a field requires ten acres or more. The fare is very poor at that.

As a result, this logical problem arises. Is there some method of handling these non-arable areas so that they will maintain
permanently a desirable plant cover? In other words, by a careful study of plant succession in pastures, will it be possible to determine the factors involved in changing a cover from worthless weeds to one of bluegrass and white clover, or vice versa?
C. A REVIEW OF INVESTIGATIONAL WORK BEARING UPON THE PROBLEM.

The problem under consideration is obviously one of plant succession on pasture land. Therefore, a review of literature should consider the principles of succession together with a survey of experimental work on grazing areas.

Succession in General.

Clements (10), in a rather exhaustive treatise on the subject, states that since succession is a series of complex processes, it follows that there can be no single cause for a particular sere. One cause initiates a succession by producing a bare area, another selects the population, a third determines the sequence of stages, and a fourth terminates the development. The initial causes of succession depend upon the reaction which each stage exerts upon the habitat.

By reaction is meant the effect which a plant or a community exerts upon its habitat. According to Clements, reactions may be classified in two groups, - soil and air.

A. Soil reactions are produced

1. By a change in soil formation
2. By a change in soil structure,
either through the addition of humus or compacting of the soil
3. By a change in water content
4. By a change in nutrients and solutes
5. By soil organisms
E. Air reactions are produced

1. By a change in light
2. By a change in humidity, temperature or wind
3. By a change in local climate
4. By a change in aerial organisms.

Clements (9), in his work on plant indicators shows that each plant or community serves as the immediate indicator of a factor or group of factors. Thus there are indicators of aeration, lime, temperature, light, water, fire, grazing, organisms, etc.

Succession in Pasture Cover.

The studies of Wiggans (39) on the various factors influencing the yield and duration of life of meadow and pasture plants showed a transition of vegetation in a newly seeded pasture. The grass mixture used was red clover, white clover, bluegrass, orchard grass, redtop, timothy and meadow fescue. There was a predominance of red clover the first year. This disappeared the second year. Following this there was a slow appearance of white clover. There was an irregularity in its production the following years. After the second year the coarse grasses became dominant only to disappear slowly in succeeding years. This was accompanied by the gradual appearance of bluegrass. This succession resulted ultimately in a bluegrass pasture containing some orchard grass and white clover. In later years, unless methods of maintaining good stands were used, there was a gradual increase in weeds.

Dickey (16) reports that for every 1,000 pounds of meat and every 10,000 pounds of milk produced on pasture there is removed with
it the equivalent of 100 pounds of 16% acid phosphate. In addition, large amounts of calcium, potassium and nitrogen are carried off. Bluegrass and white clover may do well on rich soils even where there is a lime requirement of 2,000 to 3,000 pounds of limestone per acre. They will not thrive on soils both poor and acid, however. Lack of lime is indicated by the appearance of moss, redtop, cinquefoil and sorrel. Lime, especially in the caustic form, seems very detrimental to the growth of moss. Heavy applications of burned lime to "moss hums" may kill the moss and bring in good grass. Top dressings of 300 - 400 pounds of acid phosphate in connection with lime and seed have brought in an almost solid stand of white clover in one year on impoverished hillsides formerly covered with poverty grass and cinquefoil.

Where moss, cinquefoil and ferns in a pasture indicate acid conditions, Adams (2) recommends the use of 1500 pounds per acre of hydrated lime or 2,000 of ground limestone. If conditions of the field are such that the material must be applied as a top dressing, at least three years will be required to get results.

Abbott (1) topdressed one pasture in a limestone region at Great Barrington, Massachusetts, at the rate of 2,000 pounds per acre of acid phosphate. A marked stimulation of white clover resulted.

See figures 1 and 2. The following season the cattle were fenced out of this area. The growth was harvested June 16 and August 1. Following are the results in pounds per acre of dry matter.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilized area</td>
<td>1,515</td>
<td>1,328</td>
<td>2,843</td>
</tr>
<tr>
<td>Unfertilized area</td>
<td>426</td>
<td>358</td>
<td>794</td>
</tr>
</tbody>
</table>
General view of pasture at Great Barrington, Massachusetts, where Abbott obtained marked results with top dressing of acid phosphate. Note typical Dover series topography and also limestone boulders scattered about the field.
Figure 2. Comparison of yield and cover on treated and check plots of Great Barrington pasture. The area to the left received acid phosphate as a top dressing at the rate of about 2,000 pounds per acre. The area to the right was untreated. Photograph taken about fourteen months after application of acid phosphate.
The percentage composition of the dry matter showed an increase of 8.8% of protein and 1.6% of ash in the fertilized area. There was a decrease of .52% in fat, 9.66% in extract and .24% in fiber.

White (36) has studied the growth and composition of clover and sorrel as influenced by varied amounts of limestone. In areas where the acidity approached the equivalent of 3,500 - 3,800 pounds of calcium carbonate per acre, seven inches (Modified Veitch Method) clover failed and sorrel took its place. A series of pot cultures further established this fact. Sorrel is not a calcifuge, as was shown by this greenhouse work, but has the property of adaptation under soil conditions unfavorable to the growth of most field crops.

In studying the irregular growth of clover on Mitchell Field A White (37) found that it was associated with an unequal distribution of basic material in the soil. Furthermore, the limit of acidity for clover seemed to vary with the fertility of the soil. High clover yields were associated with high applications of limestone. The highest nitrogen and phosphorus applications, on the other hand, did not go hand in hand with the highest yields of clover.

Recommendations for improving West Virginia pastures (13) point to the doubtful value of lime alone in bringing in clover. In a few instances there are striking exceptions to this rule. Used in conjunction with acid phosphate, however, lime is usually beneficial.

Work in Virginia (23) on the management and fertilization of bluegrass pastures may be summed up in the following way. Alternate grazing is of doubtful value. Fertilizers containing phosphorus in ready available form should give profitable returns when applied to run down or heavily grazed bluegrass pastures. Those results were obtained
on a limestone soil.

The English work on pastures is particularly significant. According to the Cockle Park "Guide to Experiments" for 1925 (12), the great bulk of poor pastures on the heavy soils of Northumberland can be most economically improved by the use of basic slag. On light soils the same fertilizer plus potash is the most effective treatment. Even eight successive dressings of slag are quite effective. Finely ground mineral phosphates are comparable to the slag. Slag has proved more effective than bone meal both on light and heavy soils.

On the Hanging Leaves Pasture of these same Cockle Park experiments, basic slag has proved the most effective treatment. The soil is deficient in nitrogen. This is abundantly collected by the roots of the clovers which are stimulated by the slag. That probably accounts for the low returns from cotton cake and fish. One noticeable result on this pasture has been the disappearance of rushes on the undrained land where basic slag was applied.

Again, in the Rothamsted Station Report for 1923 - 1924 (26), we read that basic slag produces excellent results on many pastures, especially on boulder clay where there is much bent grass and little wild white clover. Failure to act may be due to soil acidity or insufficient potash.

Warren (33) has pointed out that where the relation of soil organisms is more or less symbiotic, their general effect is first to increase the dominance of the host plant but finally to favor species with higher nitrogen demands. Legumes are able to grow in the poorer soils by virtue of their symbiotic partnership and consequent nitrogen
production. Thus they make possible the greater development of grasses before which they disappear, sometimes completely.

Skinner and Noll (29), investigating pasture cover on a Hagerstown loam derived from the weathering of limestone, found at the end of seven years that grass generally dominated clover in plots receiving high ratios of nitrogen. Clover persisted in the struggle for existence most easily in the plots fertilized with mixtures of phosphorus and potassium with no or small amounts of nitrogen, and decreased as the nitrogen content of the fertilizer increased.

Barnes (3) accounts for the deterioration of pastures in the following way. As a result of the loss of phosphorus and calcium due to grazing, the pasture eventually reaches a point where clovers can no longer survive in competition with more hardy but less desirable vegetation. Therefore, the nitrogen supply of the soil soon becomes too low for bluegrass. The alternating of bluegrass and white clover in good pastures is probably due to the accumulation of nitrogen by the clover which, in turn, stimulates the bluegrass until the supply becomes depleted. No data are presented to support this hypothesis, however.

On the Roberts Pasture at Cornell University (25), results were obtained by scattering clover seeds in the early spring, grazing in the spring only after good growth was made, liming the mucky areas and applying a dressing of ground bone when the pasture was new.

Eden (17) studied the edaphic factors accompanying the succession after burning on Harpenden Common. The floristic succession of vegetation after periodical fires was Rumex acetosella (sorrel), Holcus lanatus (velvet grass), and Agrostis. Of the factors influenced
by burning, those of soil reaction and humus content showed a gradation accompanying the progress of the succession.
Conclusions from Literature Reviewed.

1. Succession is a product of several factors rather than one.

2. Continuance of succession depends upon the reaction which each sere exerts upon the habitat. In the problem under consideration, the reactions are probably a combination of some of the following:
   a. Change in soil structure.
   b. Change in water content.
   c. Change in nutrients and solutes.
   d. Change in soil organisms.

3. A plant or community should be the indicator of some factor or group of factors.

4. There is a succession in pasture areas which, under conditions of neglect, terminates in a cover of worthless weeds.

5. Moss and cinquefoil in such areas should serve as immediate indicators of a factor or group of factors.

6. Pasturing removes larger amounts of phosphorus and calcium than are returned in the process of grazing. As a result, conditions become unfavorable for the dominance of white clover and bluegrass.

7. Phosphorus, preferably applied as basic slag or acid phosphate, stimulates the growth of white clover in many instances.

8. There is evidently a pH limit above which white clover will not thrive.

9. If conditions are made favorable for the growth of white clover, the nitrogen accumulated by symbiosis will in time result in the dominance of a plant with a high nitrogen requirement.
10. Nitrogen stimulates bluegrass. An accumulation of nitrogen probably accounts for the fact that bluegrass usually follows white clover in succession in pastures. This statement is more or less empirical, however.

11. Success with applications of potassium varies somewhat with the area under consideration. It is especially beneficial on light soils.

12. Clover seed scattered over a pasture in spring may speed up the succession.
A review of the literature affords ample proof that it is possible to change the flora of any given pasture by treatment or neglect. The investigations are disappointing, however, in that they do not record the causes of change further than to say that such and such a fertilizer was beneficial, or, more often, profitable under the economic conditions of the time. In most cases the investigators do not consider the pasture from the standpoint of the type of soil or the desirable and undesirable types of growth found on it. Usually the field is looked upon as a unit. Given any area, the method of procedure seems to be to try out different fertilizers alone and in combination, in hopes of finding some treatment that will be effective. This necessitates a new experiment on each pasture under consideration.

There is an ignorance of the ecological factors, especially those of the soil, which determine the dominance of one type of plant over another in our pasture cover. The reactions which the desirable and undesirable plant communities exert upon the habitat, together with the soil requirements of each group, must be known. Until these are explained it is doubtful if we can scientifically control or even account for plant succession in grazing lands.

One of the most undesirable, and at the same time abundant, covers on our New England pastures is that of moss. The most desirable growth, on the other hand, is bluegrass and white clover. A review of literature reveals only scattering information on the ecological factors determining the growth and succession of these plants. In attacking the problem, therefore, certain preliminary investigations
and observations were necessary in order to aid in formulating a working hypothesis to account for the gradual dominance of one type of growth over the other.

1. THE HOBART PASTURE.

Figure 3 is a photograph of a representative area in a field hereafter known as the Hobart pasture in North Amherst. The dominant vegetation is moss (Polytrichum commune). There are also scattering plants of running cinquefoil, sorrel, and redtop. Figure 4, a photograph taken at the same time, shows the cover in a small circular area within the above field. Estimated percentages of the types in this community were as follows:

- bluegrass 75%
- redtop 10%
- white clover 10%
- worthless weeds 5%

The history of this field is interesting. The soil is a stony, fine sandy loam of glacial till origin. The topography is drumloidal. About thirty years ago the field was plowed for crops. The area was so stony, however, that it was allowed to revert to permanent pasture. Eventually, moss established itself as the dominant growth. Approximately ten years ago the owner hauled a couple of dead cows to the area shown in figure 4. Scavengers consumed most of the flesh. The bones were covered with yellow dock that was picked out of an adjoining mowing, and all was burned. Today that bonfire area stands out as a perfect bluegrass and white clover sod closely grazed by the cows, whereas the remainder of the
Figure 3. Typical cover of the Hobart pasture. Practically the total growth is hairy cap moss (Polytrichum commune). Only occasionally may plants of sorrel, running cinquefoil and redtop be seen.
Figure 4. Typical cover of the bonfire area on the Noburt pasture. Estimated percentage of the types in this community are bluegrass 75%, redtop 10%, white clover 10%, and worthless weeds 5%.
field is still a worthless cover of moss.

In order to investigate the causes of this succession which followed the burning on the Hobart pasture, a series of greenhouse and field experiments were planned. In the greenhouse, moss, bluegrass, and white clover were used as plant indicators. In the field the original cover of the pasture was taken.

a. GREENHOUSE INVESTIGATION ON HOBART PASTURE.

Procedure

Forty-nine one-gallon crocks were filled with surface soil taken from the moss area of the Hobart pasture. Fragments of moss roots about one inch long were mixed with this soil. The crocks were treated as in tables 1-4. After two weeks the soil in each was carefully worked over in order to separate out the moss roots. They now carried sprouts about a half inch long. These sprouted roots were laid on the surface of each crock and covered with a thin layer of soil. Bluegrass and white clover were then seeded in. After germination the stand was thinned to approximately an equal number of each type of plant per crock.

Results of Preliminary Greenhouse Study.

Series A. Object - to study the influence of varying amounts of lime on dominance of moss, bluegrass and white clover. See table 1. There was a good germination of all three in each crock. In the untreated soil, however, the bluegrass and white clover soon turned yellow and made no further growth. Moss became dominant in this crock from the start. Beginning with the low application of lime, there was a gradual improvement in the white clover up to crock nineteen.
From there on bluegrass gradually became dominant. See figures 3 and 6. From number seven on there were no indications of burn or yellowing in either bluegrass or white clover.

Table I.

Effect of increasing amounts of lime on dominance of moss, white clover and bluegrass. Dry weight taken after four months of growth.

<table>
<thead>
<tr>
<th>Pot</th>
<th>Ca (OH)₂ Gms.</th>
<th>Ca (OH)₂ lbs.</th>
<th>Air Dry Wt. Gms. per pot</th>
<th>Dominant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>----</td>
<td>----</td>
<td>.05</td>
<td>moss</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>666</td>
<td>1.1</td>
<td>moss</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>1990</td>
<td>2.75</td>
<td>white clover</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>2664</td>
<td>3.4</td>
<td>white clover</td>
</tr>
<tr>
<td>19</td>
<td>9</td>
<td>5994</td>
<td>2.85</td>
<td>white clover and bluegrass</td>
</tr>
<tr>
<td>25</td>
<td>14</td>
<td>9324</td>
<td>3.9</td>
<td>bluegrass</td>
</tr>
<tr>
<td>29</td>
<td>18</td>
<td>12654</td>
<td>2.6</td>
<td>bluegrass</td>
</tr>
</tbody>
</table>
Figure 5. The gradual change in dominance from moss to white clover and finally bluegrass accompanying a gradual increase in application of lime.
Figure 6a. Influence of various amounts of lime on dominance in a cover of moss, white clover and bluegrass. This is a closer view of three of the pots in figure 5.
Series B. Object - to study the influence of varying amounts of lime alone and combined with a basal ration of plant food in the form of acid phosphate and muriate of potash on dominance of moss, bluegrass and white clover. See Table II. The acid phosphate and muriate of potash were applied at the rate of 3 grams and .75 of a gram. Calculated on an acre basis, this was 2000 pounds and 333 pounds respectively.

The striking result of this series was the marked increase in growth wherever the basal ration was applied in addition to the lime. See figure 7. Hand in hand with this, there was a slowing up of the dominance of the bluegrass over white clover. The crock that received the basal ration alone was somewhat better than the check. This seemed to agree with the work of White (36), who showed that the pH limits for clover varied with the fertility of the soil.
Table XI.

Effect of increasing amounts of lime alone and with a basal ration of phosphorus and potassium on dominance in moss, white clover and bluegrass.

<table>
<thead>
<tr>
<th>No.</th>
<th>Pot Ca (OH)_2 gms</th>
<th>Ca (OH)_2 lbs</th>
<th>#Basal</th>
<th>Air dry wt.</th>
<th>gms per pot</th>
<th>Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.05</td>
<td>moss</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>#</td>
<td>2.05</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>1998</td>
<td>-</td>
<td>2.75</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>1998</td>
<td>#</td>
<td>9.5</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>9</td>
<td>5994</td>
<td>-</td>
<td>2.85</td>
<td>bluegrass &amp; white clover</td>
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</tr>
<tr>
<td>20</td>
<td>9</td>
<td>5994</td>
<td>#</td>
<td>12.5</td>
<td>white clover</td>
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<tr>
<td>27</td>
<td>16</td>
<td>10,656</td>
<td>-</td>
<td>2.8</td>
<td>bluegrass</td>
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<tr>
<td>28</td>
<td>16</td>
<td>10,656</td>
<td>#</td>
<td>10.15</td>
<td>bluegrass</td>
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Figure 7. Comparison of cover in pots receiving lime alone and that where a basal ration of acid phosphate and muriate of potash was used in addition to the lime.
Series C. Object - to study the influence of varying amounts of phosphorus alone and combined with a basal ration of lime and muriate of potash on the dominance of moss, white clover and bluegrass. See Table III. The lime was applied as the hydrate, six grams per pot or 3,996 pounds per acre. The muriate of potash was used at the rate of .75 of a gram per crock or 333 pounds per acre.

Growth in this series after a month and a half showed a development and dominance in pot 41 and its check 42 nearly comparable to that in 37 and 43 in which lime and potassium had been applied in addition to phosphorus. See figure 8. Pots 33 and 39 were inferior. They had turned a pale, sickly yellow. What bluegrass was present was browned at the tips. Beginning at this time, however, pots 41 and 42 rapidly fell behind 37 and 43. The growth assumed a yellow cast and pinched appearance.

During the first part of the experiment, everything pointed to the fact that phosphoric acid in large applications would not only cause a dominance in clover but also produce a favorable growth. This suggested a soil deficient in phosphoric acid. A determination of total phosphoric acid gave a result of .153%, however. This is close to the average for Massachusetts soils.

The rapid deterioration of the clover in the acid phosphate pots during the later stages of the experiment indicated that a phosphoric acid deficiency was not the limiting factor. It suggested, rather, the development of a condition that was toxic to the plants. Burgess and Pember (8) found that heavy applications of acid phosphate exerted a decidedly depressing initial effect upon the solubility of aluminum. This was transitory, however.
Table III.

Effect of increasing amounts of phosphorus alone and together with a basal ration of lime and potassium on dominance in moss, white clover and bluegrass.

<table>
<thead>
<tr>
<th>Pot No.</th>
<th>Acid Phosphate gms. per pot</th>
<th>Acid Phosphate Lbs. per acre</th>
<th>#Basal Ration gms. per pot</th>
<th>Air Dry wt.</th>
<th>Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>666</td>
<td>666</td>
<td>1</td>
<td>.05</td>
<td>moss</td>
</tr>
<tr>
<td>33</td>
<td>666</td>
<td>666</td>
<td>1</td>
<td>moss and white clover</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>666</td>
<td>666</td>
<td>7.9</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>1998</td>
<td>1998</td>
<td>1.75</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>1998</td>
<td>1998</td>
<td>12.65</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>6660</td>
<td>6660</td>
<td>4</td>
<td>white clover</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>6660</td>
<td>6660</td>
<td>14.4</td>
<td>white clover</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Comparison of cover in pots receiving acid phosphate alone and that where a basal ration of lime and muriate of potash was used in addition to the lime.
After about three months, re-solution of aluminum commenced and progressively increased.

Thus a temporary depression of soluble aluminum by the large application of acid phosphate in pots 41 and 42 might explain the early development of the clover. See figure 9. As re-solution began, the plants deteriorated. This hypothesis is further supported by the work of Ruprecht (27) who found that aluminum sulfate when present in culture solutions in concentration greater than 40 P.P.M. of aluminum was decidedly toxic to clover seedlings.

Series D. Object - to study the influence of varying amounts of potassium alone and combined with a basal ration of lime and phosphorus on dominance of moss, white clover and bluegrass. The lime was applied as the hydrate, six grams per pot or 3.996 pounds per acre. Phosphorus was supplied in acid phosphate used at the rate of three grams per pot or 2,000 pounds per acre. See Table IV.

The striking result of this series was the lack of response from the potassium, even in high applications. Only when it was combined with the basal ration was a favorable growth developed. See figures 10 and 11.
Figure 9. Influence of increasing amounts of acid phosphate on a cover of moss, white clover and bluegrass. At the time the photograph was taken, all growth was a sickly yellow in color.
Table IV.

Effect of increasing amounts of potassium alone and together with a basal ration of lime and phosphorus on dominance in moss, white clover and bluegrass.

<table>
<thead>
<tr>
<th>Pot No.</th>
<th>Muriate of Potash</th>
<th>Muriate of Potash</th>
<th>Basal Ration</th>
<th>Air Dry wt.</th>
<th>Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gms. per pot:</td>
<td>Lbs. per acre:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.05</td>
<td>Moss</td>
</tr>
<tr>
<td>45</td>
<td>.75</td>
<td>333</td>
<td>---</td>
<td>.45</td>
<td>Moss</td>
</tr>
<tr>
<td>46</td>
<td>.75</td>
<td>333</td>
<td>#</td>
<td>13.8</td>
<td>White clover</td>
</tr>
<tr>
<td>47</td>
<td>2</td>
<td>1332</td>
<td>---</td>
<td>.2</td>
<td>Moss</td>
</tr>
<tr>
<td>49</td>
<td>2</td>
<td>1332</td>
<td>#</td>
<td>12.35</td>
<td>White clover</td>
</tr>
</tbody>
</table>
Figure 10. Influence of increasing amounts of muriate of potash on a cover of moss, white clover and bluegrass. Note the lack of response to this treatment.
Figure 11. Comparison of cover in pots receiving muriate of potash alone and that where a basal ration of lime and acid phosphate was used in addition to the muriate of potash.
Conclusions from Preliminary Greenhouse Investigation of Hobart Pasture Soil.

1. Untreated, this soil is too acid or toxic to grow white clover and bluegrass.

2. This unfavorable condition may be remedied by the use of lime.

3. Gradually increasing the lime content brings about a changing dominance ranging from moss through white clover to bluegrass.

4. After this acid or toxic condition is corrected, the luxuriance of growth depends upon the fertility of the soil.

5. Heavy applications of acid phosphate, even without lime and potassium, stimulate clover markedly for a short time. Thereafter, the clover loses its vigor. This phenomenon seems to indicate that the phosphorus exerts some influence on the clover outside that of a plant food.

6. Potassium alone is not effective on this soil during the life of the experiment.
b. FIELD INVESTIGATION ON HOBART PASTURE.

Procedure.

In order to investigate the reaction of pasture cover to fertilizer tests under field conditions, two series of thirty plots each were staked out on the Hobart pasture. Series B was the duplicate of A. Each plot was ten feet square. One series was located on the westerly slope of the drumloid ridge, the other on the top. During the week of April 27, 1924, these plots were top dressed according to the outline in Table V. At this time the cover of the field was beginning to show signs of growth. About a month later, after there had been one or two good rains to work the fertilizer into the soil, bluegrass and white clover seeds were scattered over the surface of the mossy cover of plots 23 - 30 inclusive, series A and B. The seeds were not worked into the soil at all. These plots, together with those numbered 8 - 15, had received the medium applications of fertilizer. Thus, by a comparison of the two groups, the influence of seeding could be demonstrated.

Preliminary Results.

The first studies on the plots were made June 3, 1924, in connection with the killing of the moss. Wherever the muriate of potash had been used, even in low applications, the moss had turned brown and apparently died. The acid phosphate was effective to a much smaller degree in bringing about this condition. There was no correlation between the killing of the moss and the use of ground limestone.

The remainder of the growing season of 1924 was abnormally dry. No further development was made on the Hobart area. Apparently the seeding in of bluegrass and white clover had not been effective.
Table V.

Treatment of plots on Hobart Pasture

Figures represent pounds per acre.

<table>
<thead>
<tr>
<th>Plot No</th>
<th>Ground Acid Muriate of White Clover &amp; Bluegrass seed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Limestone Phosphate Potash</td>
</tr>
<tr>
<td>1</td>
<td>---        ---          103</td>
</tr>
<tr>
<td>2</td>
<td>---        ---          ---</td>
</tr>
<tr>
<td>3</td>
<td>1740       ---          ---</td>
</tr>
<tr>
<td>4</td>
<td>1740       435          ---</td>
</tr>
<tr>
<td>5</td>
<td>---        435          109</td>
</tr>
<tr>
<td>6</td>
<td>1740       ---          108</td>
</tr>
<tr>
<td>7</td>
<td>1740       435          109</td>
</tr>
<tr>
<td>8</td>
<td>---        ---          216</td>
</tr>
<tr>
<td>9</td>
<td>---        1740         ---</td>
</tr>
<tr>
<td>10</td>
<td>2480       ---          ---</td>
</tr>
<tr>
<td>11</td>
<td>2480       1740         ---</td>
</tr>
<tr>
<td>12</td>
<td>---        1740         216</td>
</tr>
<tr>
<td>13</td>
<td>2480       ---          216</td>
</tr>
<tr>
<td>14</td>
<td>2480       1740         216</td>
</tr>
<tr>
<td>15</td>
<td>---        ---          ---</td>
</tr>
<tr>
<td>16</td>
<td>---        ---          435</td>
</tr>
<tr>
<td>17</td>
<td>---        5220         ---</td>
</tr>
<tr>
<td>18</td>
<td>10,875     ---          ---</td>
</tr>
<tr>
<td>19</td>
<td>10,875     5220         ---</td>
</tr>
<tr>
<td>20</td>
<td>---        5220         435</td>
</tr>
</tbody>
</table>

(Table V continued on next page)
### Table V (continued)

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Ground Limestone</th>
<th>Acid Phosphate</th>
<th>Muriate of Potash</th>
<th>White Clover Seed</th>
<th>Bluegrass Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>10,875</td>
<td>---</td>
<td>425</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>22</td>
<td>10,875</td>
<td>5220</td>
<td>425</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>23</td>
<td>---</td>
<td>---</td>
<td>216</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>24</td>
<td>---</td>
<td>1740</td>
<td>---</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>25</td>
<td>3480</td>
<td>---</td>
<td>---</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>26</td>
<td>3480</td>
<td>1740</td>
<td>---</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>27</td>
<td>---</td>
<td>1740</td>
<td>216</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>28</td>
<td>3480</td>
<td>---</td>
<td>216</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>29</td>
<td>3480</td>
<td>1740</td>
<td>216</td>
<td>Seed</td>
<td>---</td>
</tr>
<tr>
<td>30</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Seed</td>
</tr>
</tbody>
</table>
Without doubt seeding should have been done earlier in the year than the first of June.

The season of 1925 was more favorable for the growth of pastures. Marked changes took place on the treated plots during that year. Accurate measurement of the extent to which succession had taken place was impossible because the cows kept the treated plots closely grazed. It was evident that, if this measurement was to be made, the areas would have to be staked off and allowed to grow for a month or two.

Even under grazed conditions some results were striking, however. At last seeding in of white clover showed its effects. It was dominant in those plots receiving the combination of three elements - calcium, potassium, and phosphorus - plus seed. Similarly treated plots without seed, however, contained no white clover. In these, redtop predominated. Seeding plus the use of either calcium, potassium or phosphorus alone was relatively ineffective in bringing in white clover. Where any two of these were combined, some results were obtained, but none comparable with the combination of all three.

These further points were worthy of note. The suppression of the moss by the muriate of potash and acid phosphate noticed in 1924 was apparently only temporary. Ground limestone alone was relatively ineffective in changing the plant community. Where potash and acid phosphate were applied in combination, redtop established itself as the dominant cover. This was less noticeable where either was used alone. The above observations were made on the plots that did not receive seed.
In the spring of 1931 the Massachusetts Experiment Station began a series of fertilizer tests on an area hereafter known as the Tillson pasture. This was likewise of a drumloid topography, probably of glacial till origin, of about the same texture as the Hobart pasture and about a mile distant from it. The area had previously been a woodlot. The dominant cover to be noted between the stumps at the beginning of the experiment was running cinquefoil and hairy cap moss. See figure 12.

Fertilizer, alone and in combination, was applied at the following rates. In the case of acid phosphate and muriate of potash there were two rates, one low and one high.

Acid phosphate - 480 and 960 pounds per acre.
Muriate of potash - 80 and 160 pounds per acre.
Ground limestone - 2400 pounds per acre.

Following the application of these materials as a top dressing, there was a gradual change in the character of the plant population (figure 13) until in 1923 white clover established itself as the dominant growth. See figure 14. According to Director Haskell (22), the muriate of potash was most effective in bringing about this succession. Acid phosphate and ground limestone, used alone or together, were relatively ineffective. Combinations of these with potash were markedly better than potash alone, however.

It is significant to note that during 1924 there was a gradual change in dominance from white clover to bluegrass. By the spring of 1925 this succession was nearly complete. Very little white clover was in evidence.
Figure 12. Typical cover on the Tillson pasture before treatment. Note the abundance of running cinquefoil.
Figure 13. Photograph of the identical area shown in figure 12, taken one year after treatment. Note gradual change in relative abundance of white clover and running cinquefoil.
Figure 14. Photograph of the identical area shown in figures 12 and 13, taken two years after treatment. Note the complete dominance of the white clover.
An examination of the area in the fall of 1925, however, showed that clover was again becoming prominent on the better fertilized areas. Moreover, this development was rather closely associated with the applications of lime wherever used in connection with plant food. The most effective treatment seemed to be lime, potash and acid phosphate. The lime plus potash plots might be grouped second, and the lime plus acid phosphate plots third.

3. GENERAL OBSERVATIONS ON PASTURE AREAS ABOUT AMHERST.

Several pasture areas in the vicinity of Amherst are completely cut up by mossy hummocks and cow paths. In some cases, these hummocks seem to be the remains of old stumps, shrubs or bogs. This suggestion was also advanced by Gustafson (20). In other cases, however, investigation of hummocks does not disclose any trace of this former growth. The following hypothesis is suggested to explain such instances. Many new pastures, especially those that were formerly wooded, are in a loose, soft condition due to the accumulation of leaf mold and to root action. The repeated walking of cows in definite paths has gradually compacted and lowered certain of these parts, and left others as elevations or hummocks. It is significant to note that in time the cow paths become grassy. Many of them even support a good growth of white clover. The hummocks, however, remain in their former mossy state.

A similar phenomenon, though less marked, exists on the treated plots of the Tillson pasture. Around stumps, over old roots and stones, there is a cover ranging from nothing to moss, weeds and wild grasses. Other areas, lower, more compact and free from
these objects, support a good stand of white clover and bluegrass.

The following hypotheses are advanced to account for these mossy hummocks in pastures and lack of uniformity of cover in the treated plots.

1. Due to unfavorable texture, loose structure and poor capillary attraction, bluegrass and white clover are unable to establish themselves on these areas.

2. These spots are the remains of decayed stumps, limbs or roots. Certain toxic materials are present which are inimical to the growth of bluegrass and white clover.

Of these two hypotheses, the former seems the more plausible. It is no uncommon experience to note a change in cover even after teams have been driven across mossy pastures. In time the old wheel tracks grow up to grass and occasional plants of white clover, though the other parts of the fields remain unchanged. Evidently the physical condition of a soil exerts an important influence in determining the plant community.

This further point is worthy of consideration, though it is not directly tied up with pastures. Under the drip of the eaves, or where the gutters deposit the drainage from roofs, hairy cap moss frequently displaces the bluegrass and white clover of the lawn.
E. DEVELOPMENT OF WORKING HYPOTHESIS.

From a review of the literature and a study of the preliminary investigations on pasture cover, the following hypothesis was developed to account for the deterioration and rejuvenation of pasture areas.

1. Due to acidity per se or toxicity accompanying acidity, certain soils gradually develop a condition inimical to the growth of white clover and bluegrass. This situation is aggravated by the gradual loss of plant food due to continuous grazing. In such cases, moss and running cinquefoil usually replace the desirable cover. If this unfavorable acidity is corrected, however, white clover and bluegrass will again become dominant provided plant food is present in sufficient amounts to produce vigorous growth.

2. On a particular soil, any one or any combination of these above mentioned factors may determine the succession. Moreover, all soils vary in the extent to which any one of these factors may be limiting.

3. Certain physical factors, such as the texture or structure of the soil, may operate to check succession, even after the chemical requirements are satisfied.

4. Even with all other conditions ideal, a lack of seed or subordinate white clover and bluegrass plants or unfavorable weather may make the succession very slow.

5. Succession in pasture cover is a product of all the above mentioned factors. On any soil, one or several of these may be limiting.
F. ELABORATION AND TESTING OF THE HYPOTHESIS.

The following section summarizes the data collected in the attempt to prove or disprove the several points established in the working hypothesis.

Discussion of Chemical Methods.

A brief discussion of the chemical methods employed in obtaining the data will be in order. The phenol-di-sulphonic acid method, described in U. S. Bureau of Soils Bulletin 31, was used in the nitrate determination. The Jones calcium acetate test was employed for the determination of lime requirement. The results are expressed on the basis of oven dry soil. Soluble aluminum was determined by the Burgess method (7). The measurement of hydrogen-ion concentration was more of a problem. The method suggested by Wherry (35) was first tried. This was not particularly satisfactory. According to the experience of the Fertilizer Control Laboratory, the hydrogen-ion concentration of some of these soils could not be accurately measured by the potentiometer. Therefore, that method was abandoned. As a last resort, the double wedge comparator was used. The solution was made up at the rate of one part of soil to ten of water. The soils came within the range of Brom cresol green. Some objections have been raised against this indicator. For example, it gives a reading higher than that obtained when Chlor phenol red is used. It was felt that it would give the relative hydrogen-ion concentration of these soils rather accurately, however.
1. **THE ROLE OF ACIDITY AND PLANT FOOD IN THE PHENOMENON OF PASTURE SUCCESION.**

The logical place to study the influence of acidity and plant food on pasture succession would be in the pasture. There are several drawbacks to such a study, however. Certain areas make abnormal growth due to the droppings of animals. If the season happens to be very dry, experiments are slowed up by almost a year. Often chemical effects do not show for a long time on account of unfavorable weather. Moreover, the close grazing by cows makes it hard to read changes.

These undesirable conditions can be largely controlled in the greenhouse. A difficulty arises, however, in attempting to make certain other greenhouse factors comparable to those in the field. For example, the attempt to grow moss from fragments of roots placed in pots was not particularly successful. The moss came up very well but did not make a favorable growth. Again, the procedure of thoroughly mixing fertilizers with the soil in the greenhouse and then seeding to bluegrass and white clover was the very method that could not be practiced on the soil types under consideration. After some experimenting it was found that both of these objections could be overcome, however, by taking up undisturbed sods in the field and transferring them to three gallon crocks.

**Preparation of Sods for Greenhouse.**

A mossy area was selected on the Hobart pasture. Special care was exercised to have conditions uniform by choosing a spot where there were no droppings from animals. No attempt was made to disturb this area until there had been several hard fall frosts to check fur-
ther development. By October 21, 1925, all growth in the field had ceased. On that date, moss sods were taken up and placed in three gallon crocks. The moss roots were so dense that it was possible to cut out a column of just the correct size and transfer it to a crock without disturbing the structure of the soil in the least.

Greenhouse Treatment of Sods.

Sixteen crocks were filled in the manner previously described. They were taken to the greenhouse and prepared for top-dressing. The mossy cushion, which was about two inches high, was cut off close to the ground. After this was removed, the surface of the soil was loosened a little by scraping with a small weeder. The sods were then allowed to stand until new growth began to appear.

By November 6, new shoots were just breaking through the ground. That date the sods were top-dressed according to the plan outlined in Table VI. Again they were allowed to stand about two weeks. Then white clover and bluegrass seed were scattered over the surface of the crocks and gently raked into the soil. The germination of the seed was good in all cases. White clover, bluegrass and moss started off on equal terms on most of the sods. On those where muriate of potash had been applied, there was a temporary suppression of the moss, however. Acid phosphate produced this condition to only a negligible extent. It will be recalled that similar observations were made in the field.

Results After Four Months' Growth.

Photographs of this series were taken March 17. See figure 15. The air dried weight of white clover and bluegrass was
recorded wherever there had been a measurable growth. See Table VI.

**TABLE VI.**
Outline of treatment of soda from Hobart pasture.
All pots in duplicate.

<table>
<thead>
<tr>
<th>Pot Number</th>
<th>Treatment</th>
<th>Gms. per crock</th>
<th>Lbs. per acre</th>
<th>Average yield in gms. of air dry clover &amp; bluegrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Muriate of potash</td>
<td>1.4</td>
<td>3000</td>
<td>Trace</td>
</tr>
<tr>
<td>3</td>
<td>Ground limestone</td>
<td>18.2</td>
<td>3900</td>
<td>1.1</td>
</tr>
<tr>
<td>4</td>
<td>Acid phosphate</td>
<td>7</td>
<td>1500</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>a. Ground limestone</td>
<td>18.2</td>
<td>3900</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>b. Acid phosphate</td>
<td>7</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>a. Ground limestone</td>
<td>18.2</td>
<td>3900</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td>b. Muriate of potash</td>
<td>1.4</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>a. Acid phosphate</td>
<td>7</td>
<td>1500</td>
<td>Trace</td>
</tr>
<tr>
<td></td>
<td>b. Muriate of potash</td>
<td>1.4</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>a. Ground limestone</td>
<td>18.2</td>
<td>3900</td>
<td>9.82</td>
</tr>
<tr>
<td></td>
<td>b. Acid phosphate</td>
<td>7</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Muriate of potash</td>
<td>1.4</td>
<td>300</td>
<td></td>
</tr>
</tbody>
</table>
Influence of various treatments on relative growth of white clover and bluegrass on sods taken from Hobart Pasture.
A brief description of the sods will clarify the results.

That in crock 1 was a beautiful messy cushion about two inches high. See figure 16. Upon pushing aside the moss, the small white clover and bluegrass plants could be seen. They were yellow, burned and completely dominated by the moss. Determinations made on a sample drawn from the upper six inches of this sod showed that the soil had a hydrogen-ion concentration of 4.5 and a lime requirement of 2392 pounds of calcium oxide per acre.

The white clover and bluegrass on sod 2 which had received the muriate of potash were a little more prominent than on the check. See figure 16. This was not due to a better growth, however, for the plants were yellow and sickly. Rather, it was on account of the poor development of the moss which had been temporarily suppressed by the fertilizer. New moss shoots were coming on rapidly so that it would be only a question of time before the desirable vegetation on this crock would be subdued by the undesirable.

Sod 4, which had received the acid phosphate, was very much like the check. See figure 16. The white clover and bluegrass were completely choked out by the moss.

Of the four sods shown in figure 16, number 3, which had received the ground limestone, was by far the best. Not only were the white clover and bluegrass of a good healthful color, but also both had made some growth. The moss, likewise, was very vigorous. It really looked more healthy than on the check. Tests on the upper six inches of this soil showed a hydrogen-ion concentration of pH 4.6 and a lime requirement of 2245 pounds of CaO per acre. Obviously, the moss was not injured by the chemical changes from sod 1 to sod 3. Evidently
Figure 16. Change in cover on sods 1 - 4 shown in figure 15. Photograph taken after four months of growth in the greenhouse.
the dominance of white clover and bluegrass over moss is determined
by a desirable pH value for the former rather than by an undesirable
one for the latter. It should be noted further that although the
white clover and bluegrass were healthy, the total growth was low —
only 1.1 grams for the crewc. It is doubtful if sufficient growth
could ever be made under these conditions to choke out the moss.

Striking results were obtained when the ground limestone
was combined with acid phosphate. See sod 5, figure 17. The desirable
cover was absolutely dominant. By pushing aside the white clover a
few deeply buried moss plants could be seen. Most of them had died,
however.

The combination of ground limestone and muriate of potash on
sod 6 showed similar results although to a less degree. See figures 15
and 17. Evidently potassium was not as effective as phosphorus on this
soil.

Sod 7, which had received acid phosphate and muriate of
potash, was very much like sod 2. The moss had been suppressed. The
white clover and bluegrass had made practically no growth. The tell-
tale signs of unfavorable acidity, the burned tips of the bluegrass
and the yellowed leaves of the clover, indicated clearly that the
limiting factor on these sods was hydrogen ion concentration.

By far the best growth was made where ground limestone, acid
phosphate and muriate of potash were all applied. See figure 17, sod 8.
A total of 9.2 grams of dry hay was harvested. The desirable cover,
white clover and bluegrass, had obtained unquestioned possession of the
field.
Figure 17. Change in cover on sedge 5 - 8 shown in figure 16. Photograph taken after four months of growth in the greenhouse.
Conclusions from the Study of the Hobart Beds.

1. Succession from moss to white clover and bluegrass on this soil is the product of two factors, acidity and plant food.

2. The unfavorable hydrogen-ion concentration must be corrected before succession can take place.

3. After this is corrected, plant food must be added to insure dominance.

4. Phosphorus is more effective than potassium, although both are really needed.

5. Moss is not checked in any way by the application of ground limestone.

6. The above noted points support section 1 of the working hypothesis.
2. VARIATION OF THE LIMITING CHEMICAL FACTORS IN DIFFERENT SOILS.

The two chief chemical factors limiting succession in pastures seem to be those of acidity and plant nutrients. These questions arise, therefore.

a. Do these factors accompany one another, or may a first be limiting on one soil, a second on another, a third on still another?

b. Is there some way of measuring these factors chemically so that any particular problem of succession may be diagnosed on the basis of chemical tests?

Three soils were selected for study. One was taken from the pasture in Great Barrington where Abbott (1) obtained such remarkable results by top-dressing with acid phosphate. This soil was a glacial till, derived partly from limestone and classified by the U. S. Bureau of Soils as belonging to the Dover series. See figure 1. A second soil was taken just to the west of the experimental plots on the Tillson pasture. A third was selected from the Hobart pasture. A comparison of the percentage expression of the texture of these soils may be obtained from the accompanying Table VII. It will be noted that they all fall into the fine sandy loam class. The soil from Great Barrington approaches a loam, however.
Table VII.
Mechanical Analysis of Soils Studied in Greenhouse.

<table>
<thead>
<tr>
<th>Name of Soil</th>
<th>Great Barrington Per cent</th>
<th>Hobart Per cent</th>
<th>Tillson Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine gravel</td>
<td>5.64</td>
<td>2.20</td>
<td>4.75</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>7.18</td>
<td>4.30</td>
<td>8.94</td>
</tr>
<tr>
<td>Medium sand</td>
<td>9.76</td>
<td>4.55</td>
<td>8.84</td>
</tr>
<tr>
<td>Fine sand</td>
<td>18.88</td>
<td>7.25</td>
<td>12.61</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>29.10</td>
<td>60.25</td>
<td>43.85</td>
</tr>
<tr>
<td>Silt</td>
<td>22.31</td>
<td>19.69</td>
<td>10.54</td>
</tr>
<tr>
<td>Clay</td>
<td>7.13</td>
<td>1.56</td>
<td>10.47</td>
</tr>
</tbody>
</table>
Plan of the Investigation.

The investigation was outlined to study the influence of gradually stepping up the lime supply on these several soils. In all cases it was hoped that a point might be reached where white clover and bluegrass would not show signs of unfavorable acidity. Furthermore, it was hoped that such a point might be measured by a determination of hydrogen-ion concentration and lime requirement. Such determinations, in turn, might show whether or not this point, on one side of which white clover and bluegrass would make a normal development, on the other side sub-normal, was constant for the several soils. In addition, the series were arranged so that the influence of plant food in the forms of acid phosphate and muriate of potash might be studied with and without lime. Lack of greenhouse space prevented a detailed study of these elements separately. Nor was it possible to use sods as in the case of the previous study of the Hobart pasture. Instead, the soils were worked over as in the preliminary greenhouse studies. The fertilizers were thoroughly mixed with the soils. All were seeded to white clover and bluegrass. Although such a procedure was not comparable to that in the field, it was hoped that the plants would be the indicators of soil conditions. The arrangement of each series may be obtained from Tables VIII, IX, and XI. All pots were run in duplicate.

a. Results on Great Barrington Soil.

This soil, untreated, had a pH of 4.9 and a lime requirement of 2245 pounds of CaO per acre. See Table VIII. The white clover and bluegrass on the check pot gave no indications of unfavorable...
Table VIII.
Detailed Study of Great Barrington Soil.

<table>
<thead>
<tr>
<th>Pot No.</th>
<th>Treatment</th>
<th>Gms. per pot</th>
<th>Lbs. per acre</th>
<th>pH</th>
<th>Lime Req.</th>
<th>Air dry wt. of Crop. Gms. (per acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>4.9</td>
<td>2245</td>
<td>0.32</td>
</tr>
<tr>
<td>2</td>
<td>Air Slaked Lime</td>
<td>1.0</td>
<td>666</td>
<td>5.05</td>
<td>-</td>
<td>0.51</td>
</tr>
<tr>
<td>3</td>
<td>Air Slaked Lime</td>
<td>2.0</td>
<td>1332</td>
<td>5.2</td>
<td>-</td>
<td>0.48</td>
</tr>
<tr>
<td>4</td>
<td>Air Slaked Lime</td>
<td>3.0</td>
<td>2000</td>
<td>5.3</td>
<td>-</td>
<td>0.51</td>
</tr>
<tr>
<td>5</td>
<td>Acid Phosphate</td>
<td>3.0</td>
<td>2000</td>
<td>4.9</td>
<td>-</td>
<td>6.69</td>
</tr>
<tr>
<td>6</td>
<td>Acid Phosphate</td>
<td>3.0</td>
<td>2000</td>
<td>4.9</td>
<td>-</td>
<td>6.46</td>
</tr>
<tr>
<td>a. Acid Phosphate</td>
<td>3.0</td>
<td>2000</td>
<td>4.9</td>
<td>-</td>
<td>6.46</td>
<td></td>
</tr>
<tr>
<td>b. Muriate of Potash</td>
<td>0.75</td>
<td>330</td>
<td>5.2</td>
<td>-</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Acid Phosphate</td>
<td>3.0</td>
<td>2000</td>
<td>4.9</td>
<td>-</td>
<td>6.46</td>
</tr>
</tbody>
</table>
acidity. This observation is further supported by the fact that pots 2, 3 and 4, which had received gradually increasing amounts of air slaked lime, showed no improvement over the check. See figure 18. A study of pots 5, 6 and 7 is instructive. Pot 5 received acid phosphate and muriate of potash; pot 6, acid phosphate, muriate of potash and air slaked lime; pot 7, acid phosphate alone. From a study of figure 18 and table VIII, it may be observed that there was practically no difference in growth between the three pots. Thus it would seem that an application of phosphorus to this soil was as effective as phosphorus, potassium and calcium in combination. It should be noted further that any one of the last three pots produced very much more growth than any of those receiving lime alone.

Conclusions from Study of Great Barrington Soil.

1. Lime is not a limiting factor on this soil. White clover and bluegrass will do well under the hydrogen-ion concentration and lime requirement found for the check pot.

2. Phosphorus is the limiting factor on this soil. Apparently it is the only limiting factor.

b. Results on Hobart Soil.

This soil, untreated, had a pH of 4.5 and a lime requirement of 3594 pounds of CaO per acre. See table IX. The white clover and bluegrass on the check pot came up but made no further growth. At the time of harvesting, there was nothing to harvest. All indications were that the soil was too acid to permit the development of the plants. Passing from pot 1 up through 5, however, there was a gradual improve-
Figure 10. Influence of various treatments on growth of white clover and bluegrass on soil from the Great Barrington pasture.
Table IX.

Detailed Study of Hobart Pasture Soil.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>4.5</td>
<td>3504</td>
<td>Trace</td>
<td>1114</td>
<td>146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Air Slaked Lime</td>
<td>666</td>
<td>4.55</td>
<td>3293</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Air Slaked Lime</td>
<td>1332</td>
<td>4.65</td>
<td>2994</td>
<td>0.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Air Slaked Lime</td>
<td>2000</td>
<td>4.75</td>
<td>2395</td>
<td>1.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Air Slaked Lime</td>
<td>2664</td>
<td>4.85</td>
<td>2096</td>
<td>1.61</td>
<td>1128</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Acid Phosphate</td>
<td>9324</td>
<td>4.5</td>
<td>3667</td>
<td>3.02</td>
<td>1025</td>
<td>159</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


ment in the vegetation. See figure 19. This was correlated with the gradual increase in lime. The growth in pot 5 showed no signs of burning and yellowing. Thus it was concluded that by the application of air slaked lime at the rate of 2664 pounds per acre, the conditions unfavorable to clover and bluegrass had been overcome. This had been accomplished by reducing the pH to 4.85 and the lime requirement to 2096 pounds of CaO.

A Consideration of Toxicity.

Ever since the preliminary experiments, the question had remained unsettled as to whether the lack of growth on this Hobart soil was due to acidity per se or to toxicity. The series was arranged to consider this point. Pot 6 was given an abnormally heavy application of acid phosphate - 9324 pounds per acre. The response of the white clover and bluegrass to this was marked. By the end of the first month, pot 6 was the best looking one in the greenhouse. Shortly after that date, however, the growth began to turn yellow. By the time the photographs were taken, it was very sickly. Evidently stimulation had been only temporary.

Samples of soil were drawn from pots 1, 5 and 6 at the time the vegetation on 6 was at its best. A determination of nitrates showed a marked decrease from pot 1 to 6. See table X. This decrease was correlated with the increase in growth. This showed that the lack of development in pot 1 was not due to a lack of nitrification. The accumulation of nitrates in that pot was probably to be accounted for by the lack of development of the white clover and bluegrass. The air slaked lime had lowered the hydrogen-ion concentration and lime requirement, but the acid phosphate had not changed these. The tests
Figure 19. Influence of various treatments on growth of white clover and bluegrass on soil from Hobart pasture.
Table X.

Study of Acidity and Toxicity on Hobart Pasture Soil.

<table>
<thead>
<tr>
<th>Pot: Treatment</th>
<th>Gms. per Lbs. per</th>
<th>Nitrate: pH</th>
<th>Lime Req.: Sol. Al.</th>
<th>Sol. Fe.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.:</td>
<td>pot : acre</td>
<td>P.P.M.</td>
<td>:Lbs.CaO</td>
<td>P.P.M.</td>
</tr>
<tr>
<td>1</td>
<td>---</td>
<td>---</td>
<td>155.83 : 4.5</td>
<td>3594</td>
</tr>
<tr>
<td>5 : Air Slaked Lime</td>
<td>4</td>
<td>2664</td>
<td>89.23 : 4.35</td>
<td>2296</td>
</tr>
<tr>
<td>6 : Acid Phosphate</td>
<td>14</td>
<td>9324</td>
<td>19.78 : 4.5</td>
<td>3667</td>
</tr>
</tbody>
</table>

Tests for soluble aluminum and iron made by Mr. H. D. Mankins of the Experiment Station.
for soluble aluminum and iron were made by Mr. H. D. Haskins of the Experiment Station. The method was that suggested by Burgess (7). This gave the aluminum and iron soluble in 0.5 normal acetic acid. The results were high for soluble aluminum. Contrary to expectations, there was not a significant difference between pots. This may have been due to the low application of acid phosphate. Burgess (8) had used as high as 27.5 tons per acre to reduce the soluble aluminum from 820 - 697 P.P.M. In his experiment, 1000 pounds of CaO had reduced it from 820 - 645 P.P.M. However that may be, the results from these few tests of the Hobart soil were not conclusive enough to warrant the statement that the difference in growth in pots 1, 5 and 6 was due to a precipitation of soluble iron and aluminum.

As has been previously stated, the color of the vegetation on pot 5 gave no indications of an unhealthy condition. The yield was low, however. Without doubt, plant nutrients were a second limiting factor. The effect of adding phosphorus and potassium compounds to this soil in addition to the lime may be observed from figure 7. Phosphorus is probably more effective than potassium. Compare figures 9 and 10. These observations correlate well with those on the Hobart sods.

Conclusions from Study of Hobart Soil.

1. Both acidity and lack of plant nutrients are limiting factors on this soil.

2. Acidity ceases to be harmful after the pH is raised to 4.85 and the lime requirement lowered to 2096 lbs. CaO per acre.
3. Sufficient evidence was not collected to prove that the condition inimical to the growth of white clover and bluegrass was due to soluble aluminum and iron rather than acidity, although the soluble aluminum in this soil was very high.

4. Both phosphorus and potassium are needed. Phosphorus is more effective than potassium.

c. Results on the Tillson Soil.

This soil, untreated, had a pH of 4.6 and a lime requirement of 5539 pounds of CaO per acre. See table XI. The hydrogen-ion concentration was a little less and the lime requirement greater than on the Hobart soil. Under these conditions, the check pot produced 3.75 grams of air dried crop. See figure 20. That is to say, with a lime requirement of 5539 pounds of CaO per acre, this soil produced a far better growth than did the Hobart soil with one of only 3594. The vegetation on the check pot was not particularly healthy, however. There was the typical yellowing that suggested unfavorable acidity. Pot 2, with the small application of air slaked lime, was much better. From that point on, further applications of lime did not produce a noticeable change. Pot 5, with only acid phosphate and muriate of potash, also showed signs of unfavorable acidity, although considerable growth was made. Pot 6, which received acid phosphate, muriate of potash and air slaked lime, was by far the best.

This soil responded like the Hobart soil but to a much less degree. It had also been collected from a mossy area. After
### Table XI.

**Detailed Study of Tillson Soil.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Pot Treatment</th>
<th>Gms. per pot</th>
<th>Lbs. per acre</th>
<th>pH</th>
<th>Lime Req. Lbs. of CaO per acre</th>
<th>Air dry wt. of crop gms.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>4.6</td>
<td>5539</td>
<td>3.75</td>
</tr>
<tr>
<td>2</td>
<td>Air Slaked Lime</td>
<td>1</td>
<td>666</td>
<td>4.7</td>
<td>5240</td>
<td>4.75</td>
</tr>
<tr>
<td>3</td>
<td>Air Slaked Lime</td>
<td>2</td>
<td>1332</td>
<td>4.7</td>
<td>4790</td>
<td>5.31</td>
</tr>
<tr>
<td>4</td>
<td>Air Slaked Lime</td>
<td>3</td>
<td>2000</td>
<td>4.75</td>
<td>----</td>
<td>5.19</td>
</tr>
<tr>
<td>5</td>
<td>Acid Phosphate</td>
<td>3</td>
<td>2000</td>
<td>4.6</td>
<td>----</td>
<td>4.81</td>
</tr>
<tr>
<td>6</td>
<td>Acid Phosphate</td>
<td>3</td>
<td>2000</td>
<td>4.7</td>
<td>----</td>
<td>7.66</td>
</tr>
</tbody>
</table>
Figure 20. Influence of various treatments on growth of white clover and bluegrass on soil from Tillson pasture.
the experiment was completed, it was learned that this area had probably been included in a field that had been top-dressed in 1922 with either acid phosphate, nitrate of potash or both. That would account for the growth made on the check plot. Evidently this top-dressing without lime had not been successful in bringing about a succession, however. At first it seemed discouraging to find that this soil had possibly had previous fertilizer treatment. A liability became an asset, however, for out of the experiment came the suggestion that on a soil with some plant food present white clover and bluegrass may make a healthful growth with a much higher lime requirement and greater hydrogen-ion concentration than on a soil of low fertility.

Conclusions from Study of Tillson Soil.

1. Acidity is a limiting factor on this soil. To a certain small extent, plant food is limiting also.

2. This soil is more fertile than that from the Hobart pasture. Due to this fertility, white clover and bluegrass make a normal growth under more acid conditions than on the Hobart soil.

c. Conclusions from Study of Variation in Soils.

Without doubt, every pasture is a problem in itself. The chemical factors limiting succession occur in different combinations on different soils. Marked results might be obtained on the Great Barrington pasture by the use of acid phosphate. Blanket recommendations could not be made on the basis of the study of that field, however, for if they should be applied to the treatment of the Hobart pasture, results would be negligible. On the other hand, a recommendation for the use of lime based on a study of the Hobart field would be valueless if carried out
on the Great Barrington pasture. Evidently section 2 of the hypothesis, which assumed that all soils vary in the extent to which any one of the chemical factors may be limiting and also in the combination in which they occur, is sound.

This situation would not be discouraging, however, if it were possible to measure these chemical factors in terms of plant growth and make recommendations accordingly. Table XII gives data to show to what extent there is a correlation between growth and measurements of acidity. This table gives a summary of several untreated soils considered in the greenhouse. The first three have been discussed. The last two will be taken up in the section on physical factors. Evidently there is no correlation between the growth of white clover and bluegrass and the lime requirement. The Hobart soil with a lime requirement of 3594 pounds gave no growth, while a clover path with one of 9661 pounds gave good growth. Perhaps this comparison is unfair, however, because the Hobart is a mineral soil while the clover path is an organic. Nevertheless, a comparison of the Hobart and Tillson soils, both mineral, shows a similar situation, although to a less degree.

The determination of the hydrogen-ion concentration holds more promise than that of lime requirement. It is doubtful if a constant can be established, however, for the harmful effects of acidity will vary with the fertility of the soil.
Table XII.

Comparison of Various Untreated Soils Studied in Greenhouse.

<table>
<thead>
<tr>
<th>Nature of Soil</th>
<th>pH</th>
<th>Lime Requirement</th>
<th>Air Dry Wt. of Crop, Gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hobart Pasture</td>
<td>4.5</td>
<td>3594</td>
<td>Trace</td>
</tr>
<tr>
<td>Tillson Pasture</td>
<td>4.6</td>
<td>5539</td>
<td>3.75</td>
</tr>
<tr>
<td>Ort. Harrington Pasture</td>
<td>4.9</td>
<td>2245</td>
<td>.32</td>
</tr>
<tr>
<td>Clover Path</td>
<td>4.7</td>
<td>9861</td>
<td>2.70</td>
</tr>
<tr>
<td>Mossy Hammock</td>
<td>4.6</td>
<td>9731</td>
<td>2.3</td>
</tr>
</tbody>
</table>
3. THE RELATION OF PHYSICAL FACTORS TO SUCCESSION ON PASTURES.

From observations on hummocks and paths in pastures and from the lack of uniformity in the cover of plots treated alike, it might be deduced that certain physical factors rather than chemical were exerting a dominant influence on succession.

a. Comparison of Different Areas in Tilled plots.

If it were a physical rather than chemical factor that was causing this difference, soil taken from field areas treated alike but supporting different types of vegetation ought to give a uniform growth of bluegrass and white clover if subjected to a treatment in the greenhouse whereby physical factors were made constant.

Two plots from the treated area of the Tilled Pasture were selected for a study of this question. The field treatment of these had been as follows:

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Acid Phosphate lbs. per acre</th>
<th>Muriate of Potash 1bs. per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>480</td>
<td>80</td>
</tr>
<tr>
<td>31</td>
<td>960</td>
<td>160</td>
</tr>
</tbody>
</table>

In addition to the above materials, each plot had received on one half of its area ground limestone at the rate of 2400 pounds per acre.

Soil was selected from several spots in the limed half of these plots. In one case, it was taken from over stones and roots where wild grasses predominated. In another instance, it was removed from around decaying stumps where there was some dead moss and a few weeds. Still another sample was drawn in spots where there was a
good stand of white clover. These various soils were taken to the greenhouse. There they were carefully worked over until the structure was uniform in all cases. Duplicate one gallon crocks were then filled with each sample. All were seeded to bluegrass and white clover on October 24.

Results of Study of Tilled Tillsen Plots.

Photographs were taken of the pots on January 17. See figure 31. The crop of each was harvested and the air dry weights recorded. See table XIII. Good growth had been obtained in all cases. That on the soil from plot 31 was a little heavier than from plot 30, as might have been expected.

Chemically, there was not a great deal of difference between these areas. Determinations for nitrates did not show significant differences. They were low in all cases. Evidently nitrates were being utilized by the rapidly growing crop as fast as they were produced. There was very little difference in the pH values. The lime requirement was lower on plot 30 than on 31 but was rather uniform for each plot. In view of the uniformity of growth in the several pots and the slight variation in these soils chemically, certain conclusions could be drawn to account for the difference in the cover of the several areas under consideration.

Conclusions from the Study of Tilled Tillsen Plots.

1. From the chemical viewpoint, all areas on plots 30 and 31 are potentially capable of growing good white clover and bluegrass.

2. Therefore, lack of uniformity in the cover of these areas is evidently a physical phenomenon.
3. If this assumption be true, it supports section 3 of the hypothesis.
Figure 31. Growth of white clover and bluegrass on soil taken from areas of different cover in the treated plots of the Tillson pasture.
Table XIII.

Comparison of Areas of Different Cover on Treated Plots of Tillson Pasture.

<table>
<thead>
<tr>
<th>Pot</th>
<th>Character of Area</th>
<th>Nitrates</th>
<th>pH</th>
<th>Lime req.</th>
<th>Air dry crop Jan. 17</th>
<th>Air dry crop Mar. 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>1: Loose, stony</td>
<td>3.21</td>
<td>4.6</td>
<td>2904</td>
<td>4.21</td>
<td>5.07</td>
</tr>
<tr>
<td>L</td>
<td>2: Stump area</td>
<td>1.99</td>
<td>4.9</td>
<td>1646</td>
<td>3.64</td>
<td>4.90</td>
</tr>
<tr>
<td>T</td>
<td>3: Clover area</td>
<td>4.02</td>
<td>4.85</td>
<td>2694</td>
<td>3.09</td>
<td>4.89</td>
</tr>
<tr>
<td>P</td>
<td>4: Loose, stony</td>
<td>2.29</td>
<td>4.6</td>
<td>3092</td>
<td>5.55</td>
<td>7.82</td>
</tr>
<tr>
<td>L</td>
<td>5: Stump area</td>
<td>0.97</td>
<td>4.8</td>
<td>3317</td>
<td>6.01</td>
<td>7.85</td>
</tr>
<tr>
<td>T</td>
<td>6: Clover area</td>
<td>3.36</td>
<td>4.8</td>
<td>3092</td>
<td>3.90</td>
<td>4.34</td>
</tr>
</tbody>
</table>
Dominance in Case of White Clover and Bluegrass.

One noteworthy point developed as the above described experiment progressed. Pots 3 and 6, with the soil from the clover spots, produced a more vigorous growth of bluegrass and less vigorous white clover than the others. Although the differences were not striking at this time, they were just sharp enough to suggest the hypothesis advanced by several investigators but never carefully measured; namely, that there is a succession in pastures ranging from white clover to bluegrass. The cause given for this was that the accumulation of nitrogen by the legume fostered the dominance of the nitrogen loving grass.

With the hopes of getting a clue to the situation noted above, determinations were made for nitrates. See table XIII. The results were low and rather uniform for all pots. This might have been expected in light of the vigorous growth being made. The objection to these determinations was that they did not measure the nitrates being used by the vegetation of the several pots. That is, they did not show whether or not nitrates were being produced more rapidly in pots 3 and 6 than in the others.

Attempt to Produce Artificial Succession.

This other approach to the problem suggested itself, however. If the more vigorous growth of bluegrass on the soil from the clover areas was due to a nitrogen accumulation by the legume, it would seem that application of nitrates in gradually increasing amounts on pots 1 - 6 ought to bring about a gradual succession from
white clover to bluegrass. In order to attempt to verify this deduction, a solution of nitrate of soda was made up by dissolving eight grams of nitrate of soda in a liter of distilled water. This was applied to the pots at the rate shown in table XIV.

It should be noted that by February 2 pot 6 had received an application equivalent to 1438 pounds of nitrate of soda per acre. If applied as one treatment, this would have been sufficient to cause plasmolysis. The vegetation was allowed to grow a second time until March 15 when it was again harvested and the air dry weight recorded. See table XIII. The character of the growth in the several pots had not changed. Apparently the application of nitrate had been without results. The tendency for pots 3 and 6 to develop more vigorous bluegrass was more pronounced, however, than it had been at the time the crop was first harvested.

Beginning March 18, the application of nitrates was resumed until April 9. See table XIV. By that time pot 6 was showing the effects of an excess application. The other five were in good condition, however. The growth was mowed off April 1, and then allowed to develop until May 1. On that date the general appearance of pots 1 - 5 was similar to that on January 17. See figure 21. Pot 3 was about half clover and half bluegrass. On the others clover was dominant. Pot 6 had been eliminated by the excess application of nitrates.

Thus the attempt to produce artificial succession by the use of nitrates was unsuccessful. The experiment had been running only three months and a half. Possibly that was too short a time to produce a change. At any rate, no data were obtained to support the nitrogen hypothesis for the dominance of bluegrass over white clover.
Table XIV.

Application of nitrate of soda solution in cubic centimeters to clover and bluegrass sod.

<table>
<thead>
<tr>
<th>Pot</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>Total</th>
<th>Total gms.</th>
<th>Rate lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>17-20-22-27-31</td>
<td>18-22-23-26</td>
<td>1-5-9</td>
<td>c.e's.</td>
<td>per pot</td>
<td>per acre</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-0-0-0-0</td>
<td>0-0-0-0-0</td>
<td>0-0-0-0-0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4-10-10-10-10</td>
<td>10-10-10-10-10</td>
<td>10-10-10-10</td>
<td>124</td>
<td>0.99</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6-20-20-20-20</td>
<td>20-20-20-20-20</td>
<td>20-20-20-20</td>
<td>248</td>
<td>1.98</td>
<td>1320</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>12-30-30-30-30</td>
<td>30-30-30-30-30</td>
<td>30-30-30-30</td>
<td>372</td>
<td>2.97</td>
<td>1980</td>
<td></td>
</tr>
</tbody>
</table>
b. Comparison of Mossy Hummocks and Clover Paths.

In order to further investigate the relation of physical factors to the lack of uniformity in cover, another series of soils was collected from an untreated pasture on the Tillson farm. This area was one of the hummocks and paths fields previously described. The soil was of the same general geological formation as that of the treated Tillson plots. It was so high in organic matter, however, that it could almost be classified as a muck. This mucky condition held for the surface only. Beneath was a mineral soil.

Several spots were found on this field where the paths were perfect white clover covers, whereas a foot away on the hummocks there was nothing but hairy cap moss. Samples of soil were collected from this pasture. They were prepared in the greenhouse in the same way as those from the treated Tillson plots. All pots were set up in duplicate. See table XV.

Results of Investigation of Hummocks and Paths.

The bluegrass and white clover came up well in this series. For some unknown reason, both gradually died out of pot 2 and its duplicate. See figure 22. Thus, unfortunately, one clover path was eliminated from the experiment. Growth was slow in all the other pots. In no case was it comparable to that on the treated Tillson soils. Compare figures 21 and 22. What growth there was appeared rather healthy, however. There were no indications of the characteristic yellowing of the clover and burning of the tips of the bluegrass which go hand in hand with an unfavorable hydrogen-ion concentration. Judging from the appearance of the plants, it was a lack
Table XV.

Comparison of Mossy Hummocks and Clover Paths.

<table>
<thead>
<tr>
<th>Pot: Character</th>
<th>Nitrate: P.P.M.</th>
<th>pH</th>
<th>Lime Required: Lbs. CaO</th>
<th>Air dry weight: per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Mossy hummock</td>
<td>1.67</td>
<td>4.6</td>
<td>9731</td>
<td>2.2</td>
</tr>
<tr>
<td>2: Clover path</td>
<td>485.75</td>
<td>4.65</td>
<td>5839</td>
<td>0.69</td>
</tr>
<tr>
<td>3: Mossy hummock</td>
<td>2.06</td>
<td>4.7</td>
<td>8271</td>
<td>1.35</td>
</tr>
<tr>
<td>4: Clover path</td>
<td>222.32</td>
<td>4.7</td>
<td>9881</td>
<td>2.7</td>
</tr>
<tr>
<td>5: Mossy hummock</td>
<td>2.34</td>
<td>4.65</td>
<td>10,378</td>
<td>1.02</td>
</tr>
</tbody>
</table>
Figure 22. Growth of white clover and bluegrass on soils taken from mossy hummocks and clover paths.
of phosphorus and potassium that prevented a vigorous development. Pot 4, a clover path, was the best of the series. Number 1, from a mossy hummock, was a close second. It might be added that the growth in this series was not uniform for all pots as had been the case on the soil from the treated Tillson plots.

The greenhouse soils from these hummocks and paths were compared on the basis of nitrates, hydrogen-ion concentration and lime requirement in order to ascertain if there were chemical differences. See table XV. Evidently nitrification was very much more rapid in the soil from the paths than in that from the hummocks. As previously stated, growth was slow in all cases. If nitrates were being produced rapidly, they should have accumulated in the soil from the hummocks just as they did in that from the paths. There was very little difference in these soils from the standpoint of hydrogen-ion concentration. They were all strongly acid. Moreover, they all had an abnormally high lime requirement as is often the case in soils of high organic content. The low reading for pot 2 is probably due to the fact that it was more of a mineral soil than any of the others.

As can be seen from figure 22, clover grew on all of these pots. It should be noted that this growth was made in the face of slow nitrification, strongly acid conditions and an abnormally high lime requirement.

Conclusions from the Study of Hummocks and Paths.

1. Nitrification is more rapid in the soil from the clover paths than in that from the hummocks.

2. From the viewpoint of hydrogen-ion concentration and lime requirement, there is not a great deal of difference between the
hummocks and paths.

3. As far as determined, the chemical differences in these two types of areas are not sufficient to cause moss on the one and white clover on the other.

4. Therefore, it seems logical to conclude that the differences in the cover of the paths and hummocks are due to physical factors, probably soil structure.

5. If this assumption be true, it supports section 3 of the hypothesis.
4. INFLUENCE OF SEEDING ON SUCCESSION IN PASTURES.

In order to measure the influence of seeding on succession, the treated plots of series A on the Hobart Pasture (see Table V) were fenced off in the spring of 1986. The cover was allowed to develop until June 22 when photographs were taken and final readings made. A comparison of figures 23 and 24 shows the effect of scattering white clover and bluegrass seed over the surface of pastures in which these may be absent. Although the plots shown in these two photographs have had identical fertilizer treatment calculated to make them favorable for the growth of white clover, dominance of white clover was determined not by chemical factors but by seeding. This demonstration supports point four of the working hypothesis.

It should also be noted that there was a close correlation between field results and the greenhouse results on the Hobart sods. (See figure 15). Plots 23-30 (Table V), on which the white clover and bluegrass seed had been scattered, gave results comparable to those obtained in the greenhouse. This suggests a possible method for rapidly determining the limiting chemical factors on pastures provided it is possible to get the sods to the greenhouse.

From the study of these field plots, it was obvious that if a combination of ground limestone, acid phosphate and muriate of potash was applied, a change in cover would take place. If white clover seed were scattered on the new, dominant would be white clover. Otherwise, it would be red top. In order to determine what quantities would have to be applied to create favorable conditions, application were made in three amounts, low, medium and high. (See Table V). The low application, which consisted of 1740 pounds of ground limestone,
Plot 14 on the Hobart Pasture which received the medium application of ground limestone, acid phosphate and muriate of potash compared with plot 15 which was untreated. The dominant cover on 14 was redtop while that on 15 was moss.
Figure 34. Plot 29 on the Hobart Pasture which received the medium application of ground limestone, acid phosphate and muriate of potash plus white clover and bluegrass seed compared with plot 30 which received the seed but was otherwise untreated. The dominant cover on 29 was white clover while that on 30 was moss.
436 pounds of acid phosphate and 108 pounds of muriate of potash, produced little change in cover. The medium amount, however, consisting of 3460 pounds of ground limestone, 1740 pounds of acid phosphate and 216 pounds of muriate of potash, was as effective as the high. Somewhere between the low and medium applications, therefore, was the amount of materials necessary to produce the desired change in this particular pasture.
G. CONCLUSIONS FROM ECOLOGICAL STUDY OF PASTURE COVER.

1. Pasture succession from moss and cinquefoil to white clover and bluegrass is the product of several factors operating in different degrees and combinations on different soils.

2. For the most part, these resolve themselves into chemical and physical factors.

3. Among the chemical factors determining succession, acidity and plant food, especially phosphorus and potassium, play prominent roles. Nitrogen is significant to a minor extent.

4. A method was developed for measuring these chemical factors. Determination of lime requirement seems to be of little value as a guide to pasture treatment. Determination of the hydrogen-ion concentration, on the other hand, may indicate whether an application of lime will be beneficial or not.

5. The "nitrogen accumulation" hypothesis to account for the succession from white clover to bluegrass needs further verification.

6. Among the physical factors, soil structure and texture must be taken into consideration.

7. With all chemical and physical factors favorable, the rate of the succession from moss to a desirable cover will depend upon the extent to which seeds or subordinate plants of the desirable varieties are present.
1. No blanket recommendations can be made for the treatment of mossy or weedy pastures.

2. In any event, however, the pasture should be considered from the standpoint of the character of the soil and the cover found on it.

3. If the soil is hummocky, of coarse texture or loose structure, unsatisfactory results may be obtained even if the area is fertilized.

4. If the soil is of proper texture and structure, however, chemical treatment ought to bring about a favorable succession provided subordinate plants of the desirable types are present in the field. If they are absent, the succession may be speeded up by scattering the seed of these desirable types over the treated area.

5. The determination of the one or combination of chemical factors limiting succession will be difficult. It may be suggested that soils with a pH value around 4.5 (from cresol green used as an indicator) will respond to liming. Those with a pH value above 5 will not respond to this treatment. These two statements are based upon rather incomplete data. Plant food in the form of phosphorus and potassium will probably be required. On some heavy soils, phosphorus alone may be sufficient.

6. In the final analysis, the plant is probably the best indicator of conditions. Results from treatment should be studied on small experimental plots for a year or two before the whole field is treated.
BIBLIOGRAPHY

1. Abbott, J. B.

2. Adams, G. W.

3. Barnes, E. R.
   Permanent Pasture Economy. Ohio State University. Dept. of Soils. Timely Soil Topics No. 70.

4. Blair, A. W. and Prince, A. L.

5. Bryan, C. C.
   Effect of Reaction on Growth, Nodule Formation and Calcium Content of Alfalfa, Alsike Clover and Red Clover. Soil Science V. 15, p. 23.

6. Burgess, P. S.

7. Burgess, P. S.
8. Burgess, P. S. and Pember, F. R.
   "Active" Aluminum as a Factor Detrimental to Crop
   Production in Many Acid Soils. Rhode Island Agricul-
   tural Experiment Station, Bulletin 194.

9. Clements, F. E.
   Plant Indicators. Carnegie Institute of Washington.
   Publication 290.

10. Clements, F. E.
    Plant Succession. Carnegie Institute of Washington
    Publication 242.

11. Clements, F. E.

12. Cockle Park Agricultural Experiment Station, England.

13. Cook, I. S.
    West Virginia Pastures. West Virginia Agricultural Ex-
    periment Station. Bulletin 177.

14. Cowles, H. C.
    The Causes of Vegetative Cycles. Botanical Gazette
    V. 51, p. 161.

15. Denison, I. A.
    The Nature of Certain Aluminum Salts in the Soil and their
    Influence on Ammonification and Nitrification. Soil
    Science V. 13, p. 81.

    Renewing and Improving Permanent Pasture. Penn. State
17. Eden, T.

The Edaphic Factors Accompanying the Succession After
Burning on Harpendum Common. Journal of Ecology,
V. 12, pp. 267-286.

18. Gray, L. G. et al.

The Utilization of our Lands for Crops, Pasture and

19. Creoley, W. B. et al.

Timber: Mine or Crop? U. S. D. A. Yearbook 1922,
pp. 93-180.

20. Gustafson, A. F.

Fallen Trees a Cause of Hammock Formation. Journal
American Society of Agronomy, V. 16, No. 12, p. 782.

21. Hartwell, B. L. and Pember, F. R.

Aluminum as a Factor Influencing the Effect of Acid Soils
on Different Crops. Journal American Society of Agronomy,
V. 10, p. 45.

22. Haskell, S. B.

Research Service to Massachusetts Animal Industry.
Progress Reports. Massachusetts Agricultural Experiment

23. Hutcheson, T. B. and Wolfe, T. K.

The Fertilization and Management of Bluegrass Pastures.
Virginia Agricultural Experiment Station Report 1918,
pp. 33-47.

24. Magistad, C. C.

The Aluminum Content of the Soil Solution and its Relation
to Soil Reaction and Plant Growth. Soil Science, V. 20,
25. Roberts, I. P.


27. Ruprecht, R. W.


28. Shantz, H. L.


29. Skinner, J. J. and Noll, G. F.


30. Somerville, W.


31. Tansley, A. G.

Practical Plant Ecology. Dodd, Mead and Company.

32. Tounsey, J. W.

Foundations of Silviculture, Parts I and II. Yale Forestry School.
33. Warren, J. A.


34. Wherry, E. T.


35. Wherry E. T.


36. White, J. W.

Concerning the Growth and Composition of Clover and Sorrel as Influenced by Varied Amounts of Limestone. Penn. Agricultural Experiment Station. Annual Report 1913-1914, pp. 46-64.

37. White, J. W.


38. White, J. W. and Holben, F. J.


39. Wiggans, R. G.

Studies of Various Pastures Influencing the Yield and Duration of Life of Meadow and Pasture Plants. Agricultural Experiment Station, Ithaca, N. Y. Bulletin 424.
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