A STUDY OF SOIL CONDITIONS RESPONSIBLE FOR CLOVER FAILURE IN BRITISH COLUMBIA

-by-

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INTRODUCTION.

The nature of this problem has made it necessary to cover a large field. Reasonable success has been obtained in narrowing the problem to a few factors. Thorough or adequate consideration of these has been impossible. Further investigations dealing with the problems raised by this study appear desirable in themselves and would enhance the value of the study as a whole.

This investigation was undertaken with the consent and full cooperation of the Department of Agronomy. The author appreciates deeply the effort made by the Department to assist him in every way. In particular the author feels indebted to Dean F.M. Clement, of the Faculty of Agriculture, Dr. D.G. Laird, and Dr. G.H. Harris, as well as several farmers who supplied soil samples and data which made this study possible.

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AN HISTORICAL SKETCH OF RED CLOVER FAILURE.

The uncertainty in red clover (Trifolium pratense) production is familiar to Agronomists in most humid regions of the temperate zone. This particular forage plant, it seems, is unusually sensitive to adverse conditions which are of wide occurrence and yet whose exact nature has not been clearly defined. The trouble dates back into the centuries as Piper (1) has shown. Worlidge (2) made reference to clover trouble existing in England as early as 1669. Mention of this phenomenon in America, according to Pieters (3) was made by Jared Elliot in 1747. In 1920, "Clover Sickness" was noticed in Pennsylvania and again in 1866 in Ohio. The history of red clover failure has been traced by Fergus and Valleau (4). In both Europe and America the same trouble has been experienced with red clover, although the specific causes have probably not been similar in every case. On the American continent, where agriculture is still in its youth, this trouble has not been reported from all quarters. The seriousness of the complaint however is exemplified by Pieters (5) when he says, "The important problems in the Eastern States are associated

1. Piper, "Forage Crops." P. 412.
2. Worlidge, Syst. Agric., 1669, 24, 25.
3-5. Pieters, A.J. Sci. Agr. Vol. III. No. 12. Aug. 1923. P.405-411.
4. Fergus, E.N. and Valleau, W.D.

with red clover. --- It is true that clover failure is not yet serious in such states as Wisconsin, Minnesota and Iowa, but the complaint is moving west just as it has done for more than one hundred years."

Although, even on some of the oldest farms no serious clover troubles are encountered, reports from scattered points throughout humid British Columbia indicate that many areas are naturally poor clover soils and others are approaching this condition. The occurrence of the complaint is very irregular and we see good and poor clover soils within very short distances of each other. While consulting farmers the author has found that, while on many of the farms the clover stands are satisfactory, memory recalls former luxuriance which surpassed the present crop yields.

Very little consideration is necessary to reveal that as the years roll by British Columbia should expect her clover troubles to increase, as we see they have done in the older countries.

CAUSES OF CLOVER FAILURE.

In Europe the term "Clover Sickness" has been used to describe what has been commonly called "Clover Failure" in America. Prior to 1870, clover sickness was, as Fergus and Valleau (1) have stated, "generally considered a soils problem throughout Europe, some believing the difficulty due to the lack of some essential mineral or minerals, others attributing it to the presence in the soil of toxic material excreted by the plant. A few had other theories, but all were based on the assumption that something was wrong with the soil."

In subsequent years more progress has been made in isolating causes of clover failure. To-day, most, if not all, the causes have been suggested and a general improvement effected. The agricultural experiment stations in the Central and Eastern States have demonstrated that in many cases good yields of red clover can be grown with the correct soil treatment, but, even yet, the cultural requirements of the clover plant are far from fully understood. Especially is this true in regard to soil conditions. Pieters (2) has carefully surveyed the causes of clover failure and has grouped them under several main headings as follows:

1. Incorrect Cultural Treatment.
2. Unadapted or Poor Seed.
3. Insects, Disease and other Pests.
4. Unsuitable Soil Conditions.

1. Fergus, E.N. and Valleau, W.D. Kty. Agr. Exp. Sta. Bull. 269.
2. Pieters, A.J. U.S.D.A. Farmers' Bulletin No. 1365. 1924.

The causes to which Clover Failure is generally ascribed will be discussed very briefly in the next few pages and an attempt will be made to show the relative importance of each as a cause of clover troubles.

Incorrect Cultural Treatment.

Clover needs a good seed bed, fine on top but firm beneath. Sowing on freshly prepared ground without adequate packing is almost certain to result in failure. Since the germination of the seed is largely a matter of soil moisture conditions, the weather is a big factor. The drier the surface soil, the better the seed bed, that is necessary if satisfactory germination is desired.

It is impossible to determine how many failures are due to the nurse crop or "companion crop," especially on land of limited fertility and moisture. Pieters (1) writes, "Many observations have been made where clover has failed to make a stand when sown with a nurse crop while succeeding when seeded alone." "In general, it may be said that on fertile soil or in sections not subject to summer droughts a companion crop will not hurt the clover.

Overgrazing or cutting too late in the fall of the first year is a very common form of abuse. This treatment is most serious however in areas where severe winters are experienced. In such localities Pieters suggests leaving the stubble long to hold the snow and allowing the clover to make six inches or more of growth before winter.

1. Pieters, A.J. U.S.D.A. Farmers' Bulletin No. 1365. 1924.

Unadapted or Poor Seed.

Foreign seed (1) has been shown to be usually inferior to seed from acclimatized plants. Much of the European seed is grown in regions where milder winters are experienced than in the main clover areas of North America. Naturally the seriousness of using non-acclimatized seed would be greatest in areas subject to severe winters.

Insects, Disease Organisms and other Pests.

The clover plant is subjected to attacks from all sorts of pests. Only a few organisms, however, are known to cause serious injury. These may occur in quite local infestations only, or they may infest a wide area.

Although known to cause much injury, but rarely has complete failure been attributed to the devastations of pests or disease.

Possibly the most serious of the insect pests is the Clover Root Borer (Hylastinus obscurus). Although occurring widely it but rarely causes injury unless in the late summer of the second year (2).

The Clover Root Curculio, Sitones hispidulus (Fabr.), has been reported as harmful (3).

In England cases are on record of destruction by the Stem Eelworm, Tylenchus devastatrix. This organism is a nematode. Except in a few instances (2) the Eelworm has given but little trouble in America.

Fungus diseases cannot be dismissed as lightly. Among them is

1. Wolfe,T.K. and Kipps, M.S. Bull.252. Vir.Poly.Inst.Blacksburg,Vir.
2. Pieters, A.J. Red Clover, U.S.D.A. Farmers' Bull. 1365. P. 20.
3. Stookey, E.B. U.S.D.A. Farmers' Bull. 649. 1915.

Anthracnose Colletotrichum trifolii, a fungus disease of wide-spread occurrence. The Anthracnose belt in the United States includes the states of Kentucky, Tennessee and Virginia. In the last named state (1) this disease is one of the most serious causes of clover failure - far more important than winterhardiness.

Root Rot is attributed to any of a number of organisms in the soil. According to Fergus and Valleau (2), Root Rot of red clover is universal in regions where the plant has been long cultivated. It becomes a critical factor only when environmental conditions are unfavorable to the continuous growth of the plant. They (Fergus and Valleau) further add that the application of lime, manures and fertilizers to soils on which clover fails regularly, decreases the mortality rate of the plant.

Stem Rot, Sclerotinia trifoliorum, has also been given as a cause of clover failure (3) in England, in the Eastern States, in Canada and Oregon.

Other diseases such as leaf-spots, rusts and mildew cause some damage but rarely, if ever, are responsible for what we might call a "failure."

Unsuitable Soil Conditions.

Under this heading are grouped several factors, which may exist alone or more probably act several at a time. It is asserted by many

1. Wolfe, T.K. and Kipps, M.S. Vir.Agr.Exp.Sta. Bull. 252, 1926. P.5.
2. Fergus, E.N. and Valleau, W.D. Kty.Agr.Exp.Sta. Bull. 269.
3. Pieters, A.J. U.S.D.A. Farmers' Bull. 1365. 1924.

workers that the most important causes of clover failure fall under this category. It may well be stated at this point that, because of the great variation in soil and other conditions, under which fertilizer experiments have been conducted, no one treatment has been found which gives anything approaching consistent results.

In Kentucky (1) Fergus and Valleau concluded that "Clover failures associated with reduced soil productivity are much more widespread than failures due to other causes. ---- Clover failure results indirectly from unfavorable nutritional environment and probably directly as the result of the attack of pathogenic organisms upon the roots."

Stookey (2) reports that experiments in Washington State indicate a deficiency of some element of plant food as very probably responsible for numerous red clover failures.

It is common knowledge that red clover will not thrive on poorly drained land. Before any marked benefits can be hoped for from lime and fertilizers adequate drainage is imperative. This cause cannot, however, be responsible for increasing the frequency of clover failures because the drainage situation is being improved as agriculture progresses.

As Pieters (3) states, "Organic matter is essential to a fertile soil. It serves various purposes - to provide food for beneficial microörganisms and through them to furnish food for crop plants; to loosen up stiff soils and to make loose ones more retentive of moisture."

1. Fergus, E.N. and Valleau, W.D. Kty.Agr.Exp.Sta. Bull.269. P. 207.
2. Stookey, E.B. State Coll.Wash.Agr.Exp.Monthly Bull.May 1920. P.20.
3. Pieters, A.J. U.S.D.A. Farmers' Bull. 1365. P. 13.

The absence of organic matter causes stiff clays and silts to bake. This condition is hard on young clover plants during drought and often a crust is formed which the young plants penetrate with difficulty.

The fertility of the soil as it pertains to acidity, lime, potash and phosphate supplies logically warrants consideration and has in fact received attention by a large number of research and experiment stations.

"Lime for red clover" has become a maxim in field practice. Red clover, because it is adapted to humid climates, usually is grown under acid conditions where it generally responds to lime better than most other crops. Lyon and Buckman (1) suggest that when plants are benefitted by lime a number of possible reasons may be suggested. These they list as follows:

"(1) direct nutritive or regulatory action of the calcium and magnesium;

(2) removal or neutralization of toxins of either an organic or inorganic nature;

(3) retardation of plant diseases;

(4) increased availability of plant nutrients; and

(5) encouragement of biological activities favorable in a nutritive way to higher plants. ---- The crop response to liming is thus a complicated phenomenon and only the broadest conclusions may be drawn. As yet, inferences developed by practice are the surest guides in deciding on the responses that various plants will probably make to the addition of lime."

1. Lyon and Buckman. Revised Edition 1930. P. 293.

This summarization by Lyon and Buckman shows clearly that the true effect of high acidity on crop plants is not known. Whether it is the effect of the high concentration of hydrogen ion, an indirect effect of this or low available calcium has not been satisfactorily established.

Clover-poor soils do not always respond to lime alone. Phosphatoric acid is often the nutrient which produces the most marked response and it will do so when lime proves of very little value. Results by Fergus and Valleau (1) illustrate this point:

Plot Treatment	Clover Hay	Corn	Wheat
Check	710 lbs.	20.8 bu.	3.1 bu.
Lime	785	26.6	4.0
Check	748	25.2	4.1
Acid Phosphate	2112	41.5	7.5
Lime + Acid Phosphate	2863	46.3	10.0

Plot Treatment	Clover Hay	Corn	Soy Bean Hay
Check	106 lbs.	16.5 bu.	1630 lbs.
Lime, Manure	898	40.8	3549
Manure	336	27.1	2906
Lime, Manure, Acid Phosphate and Potash	1932	44.0	4587

An interesting point to be noted in the above experiments is the greater response to fertilizers in the case of red clover.

In Kentucky (2) Limestone and Superphosphate increased yields of hay by more than 100% in each of six trials throughout the State. In the

1. Fergus, E.N. and Valleau, W.D. Kty.Agr.Exp.Sta. Bull. 269. P.151.
2. Forty-first Annual Report.Agr.Exp.Sta. U. of Kentucky 1928. P.36.

checks very little clover was present, while on the treated plots clover predominated.

From these and similar data it is evident that the lack of both lime and phosphate has proven to be a large contributing factor in causing clover failure.

Potash fertilizers have not proven to be of value in relieving clover troubles as have lime and phosphoric acid. Clover failures traceable to a deficiency of potash have been noted in restricted areas only and are of infrequent occurrence generally. Even where response to potash is found of economical value it is more to improve a stand than to save a crop from total failure. Indeed it is generally considered sound practice to include potash in a fertilizer mixture for clovers.

Undoubtedly each of the foregoing factors is responsible for, or contributes to, the failure of clover crops. It can be said with reasonable assurance that there are other phenomena besides those enumerated which are deleterious to red clover growth. Abnormal moisture relations in the soil are harmful at times. The lack of nodule organisms or of strains which are symbiotic in the true sense would cause poor growth. Factors of this type would operate over small areas but would not be responsible for extensive failures.

As serious causes of failure Incorrect Cultural Treatments and Unadaptability of Seed must be ignored. In a developing community improvement is being effected continually in both these respects. In contrast we find that clover troubles tend to increase as an agricultural territory ages.

That insect pests or disease are not the major cause of trouble, unless in an indirect manner, is apparent when, in the field we see one plot produce good yields while its neighbor invariably is poor or when fertilizer trials on poor soils show such startling increases as clover manifests.

From a consideration of these data it appears logical to assume that the true cause or at least the predominant causes of clover failure lie in the nutritional powers and physiological qualities of a soil. It appears that associated with acidity, calcium, phosphoric acid and perhaps potash, one should be able to find the reasons for the peculiarities of clover failure.

When disease is prevalent, as Fergus and Valleau (1) have pointed out, the mortality is great in soils which are low in productivity and becomes less as the fertility is increased. Therefore irrespective of whether low soil fertility is the direct or the indirect cause of clover failure, soil treatments with manures and fertilizers seem to offer the greatest possibilities for improvement.

1. Fergus, E.N. and Valleau, W.D. Kty.Agr.Exp.Sta. Bull. 269. P.200.

WHY RED CLOVER SHOULD BE MORE SUBJECT TO FAILURE THAN MOST OTHER CROPS.

In the foregoing chapter Red Clover Failure has been shown to be traceable in most cases to a deficiency or need for some element of plant food or for lime. The principle was advanced that almost all failures can be directly attributed to unsuitable soil conditions. If such be the case the question arises as to why red clover plants should succumb to these undesirable soil conditions when other crop plants appear unaffected or suffer comparatively little. Does the soil not offer nurture to all plants alike? The following discussion is submitted as an indirect reply to these queries by attempting to show that red clover possesses idiosyncrasies of its own. Specifically what these may be remains to be seen.

The Red Clover Plant.

At this juncture a word on the growth habits and physiological requirements of the Red Clover plant would not be amiss.

Being a member of the Leguminoseae, Common Red Clover possesses the desirable characteristics of that group, including the presence of nitrogen-fixing nodules on its roots. To this single property can be attributed much of its agricultural value. Red Clover is ordinarily biennial in habit, but under conditions, as in the mountain valleys in the

Northwestern States and on the Pacific Slope, it may be perennial. The duration of growth is controlled largely by prevailing climatic conditions and by the nature of the soil. The plant flourishes where the summers are not too hot and the winters not too severe and where considerable rain falls during the growing season. When sufficient moisture is present growth is rapid and continuous from spring until early fall.

The plant depends on a strong deeply penetrating top root for much of its moisture and food supply and where this rooting system is interfered with, either through winter-bearing or because of an undesirable or impermeable sub-soil, Red Clover maintains itself with difficulty.

Experience has shown that this useful legume will grow in a considerable variety of soils, though not always equally well. Apparently, the most suitable are the heavier soils of the clay loam type which should also possess a moderately open sub-soil. A supply of moisture, lime and humus also appear desirable. Sandy soils, provided other factors such as the condition of the sub-soil are satisfactory, have proven suitable for Red Clover culture.

Sensitivity to Acidity.

The author made several excursions to the sections of the Fraser Valley in which Red Clover is grown to a considerable extent, even before undertaking a study of the Red Clover situation. During these visits to clover fields, the author was convinced that the uncertain nature of Red Clover culture was traceable to one or several factors, which were inimical to other crop plants but which produced unsatisfactory stands or complete failures in the case of Red Clover, due to a greater inherent susceptibility in that plant. If this view-point is correct, much should be gained in searching for the causes of Clover Failure by enquiring into the points where dissimilarity in the cultural requirements of Red Clover and the other common crop plants exist.

Being a crop that thrives under humid conditions, red clover is usually grown on soils possessing an acid reaction. It is a well known fact that plants differ considerably in their preference for and resistance to varying degrees of soil acidity. As yet it has proven impossible to group plants with precision according to their favorite soil pH and so they are classified generally as tolerant or sensitive to soil acid conditions. This is done in Table 1. That little success has been attained in accurately grouping crop plants in order of acid preference is an indication that possibly acidity per se is not the predominant factor controlling the distribution of plant species on soils, but has an indirect influence.

TABLE 1.

Relative Sensitiveness of Plants to Acid Soil Conditions. **

Very Tolerant	Tolerant	Sensitive	Very Sensitive
Bent Grass	Alsike Clover	Barley	Alfalfa
Blackberry	Buckwheat	Cabbage	Asparagus
Blueberry	Carrot	Mustard	Beet (Sugar)
Flax	Corn	Orchard Grass	Celery
Japan Clover	Crimson Clover	Rape	Lettuce
Lupine	Gooseberry	Red Clover	Mangel
Oats	Pea	Sweet Clover	Onion
Potato	Raspberry (Red)	Turnip	Parsnip
Red Top	Strawberry	Wheat	Spinach
Rye	Tomato	White Clover	Yellow trefoil
Watermelon	Timothy		
	Vetch		
	* Soy Beans		

Oats, potatoes, hay crops, raspberries, strawberries, fodder corn, peas and vetch are among the most successfully produced crops in the Fraser Valley. These are all classified as acid tolerant species. Root crops, vegetables and red clover are listed as acid sensitive and yet are grown to a considerable extent in the Valley. It is generally realized that root crops and vegetables require rich, fertile soils before good yields are obtainable. It would be incorrect to suggest that Red Clover is not known as a plant demanding fertile soils too. On the contrary, as was shown in an earlier chapter, cultural experiments have indicated that red clover also needs good soil conditions with an adequate food supply if

* Lyon and Buckman. P. 269.
** Baer. P. 307.

maximum yields are expected. This is generally realized but farmers as a rule are unable to supply their clover crops with optimum conditions and instead under their mixed farming system seed clover with acid tolerant species. The possibility is suggested that red clover suffers especially in the first year due to competition from oats, grasses, other clovers, et cetera, with which it is seeded, and it is unable to make sufficient progress before the severities of winter and the inroads of disease take their toll. A study of Table 1. suggests strongly that acidity in itself is a major factor in plant growth. However, it is maintained by many workers that not acidity per se but the effects of high and low acidity on the supply of plant food and also on the solubility of certain soil toxins are the factors effecting plant growth on soils of different degrees of acidity.

That plant species differ in their sensitivity or resistance to soil acid conditions is generally considered correct, especially in view of data like the following reported by the Rhode Island Station (1):

Botanical composition of hay crop seeded to Timothy, Red Top and Red Clover, with Barley as nurse crop;

		Limed	Unlimed
1st Year	Timothy	5%	-
	Red Top	45	100% (near)
	Red Clover	50	-

In the second year of grass the limed plots were a mixture of Timothy and Red Top, but consisted mainly of Red Top on the unlimed areas.

1. Hartwell, B.L. Agr.Exp.Sta. Rhode Island State Coll. Bull.186,1921.

In another case the following percentage composition by weight was found:

	Unlimed 3.2 tons	Limed 4.3 tons
Red Clover	6%	11%
Alsike	37	15
Timothy	28	61
Red Top	29	13

Plant Food Consumption.

The family Leguminoseae is very interesting when the general habits and physiological characteristics are compared to those of other families and species. As a group they are considered heavy feeding plants, extracting a large amount of nutrients from the soil. Warrington (1) (Table 2) and others have shown the great difference in plant food consumption displayed by our common crop plants.

TABLE 2.

Composition of Crops in lbs. per acre.

Crop	K	Na	Ca	Mg	S	N	P_2O_5
Wheat (30 bus.)	29.0	2.6	9.2	7.1	7.8	50.0	21.1
Oats (45 ")	46.1	5.4	11.6	8.7	8.0	52.0	19.4
Red Clover (2 tons)	83.4	5.1	90.1	28.2	9.4	98.0	24.9
Meadow Hay (1½ ")	50.9	9.2	32.1	14.4	5.7	49.0	12.3
Mangels Root and Top (22 tons)	300.7	118.7	42.9	42.5		149.0	52.9
Potatoes (6 tons)	76.5	3.8	3.4	6.3		46.0	21.5
Turnips Root and Top (17 tons)	148.0	24.0	74.0	9.5	21.0	110.0	33.0

1. Warrington, P. 72.

We see from Table 2 that a 2 ton crop of Red Clover will on the average extract from the same soil nearly ten times as much calcium and four times as much magnesium as will a 30 bus. crop of wheat. The difference is also much greater between clover and oats, meadow hay or potatoes. Root crops on the other hand also feed heavily and easily exceed clover in potash consumption but fall short in the amount of calcium taken up by an acre of crop. It might appear from these data that we have some evidence as to why red clover fails to do well on poor soils. In this regard alsike clover is held up for contrast as a plant which will thrive under fairly acid conditions. Yet analyses show us that alsike takes up nearly as much, if not more, plant food than does red clover. Jones and Bullis (1) found that red clover took up more calcium and magnesium than alsike but not as much potash, phosphate and sulphate.

TABLE 3.

Percent Minerals in Crops.[1]

Crop	K_2O	CaO	MgO	P_2O_5	SO_3
Orchard Grass	2.24	1.15	.086	.350	.120
Timothy	1.55	.108	.060	.405	.187
Red Clover	2.10	1.500	.393	.396	.232
Alsike Clover	2.72	1.260	.348	.513	.285
Alfalfa	2.25	1.760	.343	.556	.400

1. Jones and Bullis. Oregon Agr. Coll. Exp. Sta. Bull. 197, 1923.

Analyses of this sort cannot be considered absolute or representative under all conditions but do serve as an indication of the inherent differences in the food intake of various species of crop plants. Another point to be borne in mind in this regard is the rate of growth and the yield obtained per acre of crop.

From a consideration of the amounts of nutrient elements taken up by plants from the soil we realize that plants are able by some mechanism to absorb selectively, and possibilities which might have a bearing on our problem, are suggested to us.

It is desirable at this juncture to consider the factors in the soil, and within the plant itself, which control or govern the intake of plant food. There is no intention on the part of the author to cover the multitude of factors which might have a bearing on the problem. Rather it must suffice to consider the main factors concerned in the processes of absorption and growth.

In the process of nutrient extraction from the soil, the following factors are suggested as bearing considerably on the problem:

(1) The amount of available plant food and other soil material as well. The acidity of the soil has a major influence on this,

(2) The solvent action of the plant root, which may be of paramount importance,

(3) The area of root surface,

(4) The rate of root growth,

(5) The zone or soil horizon in which the plant feeds,

(6) The permeability of the root hair to soil materials.

A gradient must be maintained if continued intake of materials is to continue. Therefore from the plant side of the absorption process the following would be involved:

(1) The rate at which material is incorporated into tissue during normal anabolic processes,

(2) The rate at which material is precipitated in an insoluble form due to the change of acidity in transition from the soil solution to the plant sap.

(3) The rate at which water is transpired by the plant.

The discussion of the above factors pertains to all types of soil material, foods, toxins, apparently non-essential components of plants, et cetera.

This brief perusal of a broad field of study has been made in an attempt to enunciate factors which may have a significant bearing on the problem at hand, to wit, the reason or reasons for the differential intake, or consumption, of soil materials by various plant species. This problem, again, is being considered in the light of its bearing on the first question of "Why Red Clover is more subject to failure than are most other crops."

Several of these factors will be dismissed as appearing to have very little influence on the problem at hand. At the outset it is well to realize that plants exhibit an inherent difference in the quality of tissue metabolized within. It is true that as a rule some plants, such as the typical Cruciferae and Leguminoseae do use a greater proportion of minerals and nitrogen in their tissues than do other plants such as the cereals. They develop a more leafy type of growth, and as analyses show, synthesize a greater amount of proteins and other mineral containing compounds in their structure. It is correct to say then that these plants, which exhibit high plant food analyses, do possess an inherent anabolic rate that is higher than in other plants.

When it is decided that plants even on the same soil differ in the amount of plant food which they synthesize into their structure, the next logical step is to question how they are able to get it from the soil. We may grow two species side by side and analyse the residues after a period of time to find that one species can extract twice as much plant food as the other. Further we may assume that each has extracted as much as it is able under the existing conditions. We believe this because on the addition of the correct fertilizer each would respond to show that plant food deficiency has been the limiting growth factor. Proof of a difference in feeding power is scarcely necessary, it is so self-evident. However, analyses such as appear in Table 2 and work by Newton (1) definitely prove the point.

The question of how plants feed is a lively one at the present time. The old "soil solution" theory doesn't seem to be an adequate means of explaining the large amounts of plant food taken up by plants, especially in humid soils. Truog (2), Parker and Pierre (3), Combers (4)

1. Newton, J.D. The Selective Absorption of Inorganic Elements by Various Crop Plants. Soil Sci. Vol.26,1928.
2. Truog.
3. Parker, F.W., and Pierre,W.H. Soil Sci. Vol.25, P.337. 1928.
   __________ Soil Sci. Vol.24, P. 129, 192. 1927.
4. Comber, N.M. Jour. Agr. Sci. Vol. 12, 363-369. 1922.

and others are of the opinion that the plant must depend on a root-soil contact if sufficient nutrient, especially PO_4, is to be absorbed. It has been shown that plants secrete CO_2 and also exert a solvent action on the soil mineral matter. The etching on marble is proof of this. Marias (1) has shown that plants do not readily use insoluble phosphates unless there is contact between the roots and the phosphate particles. Tidmore (2) found better growth in soils whose displaced solution contained from 0.02 to 0.03 p.p.m. inorganic PO_4 than in culture solutions at 0.1 p.p.m. P.O.4. Metzger (3) found a greater concentration of bicarbonates close to plant roots than at a distance of four inches away, due undoubtedly to the solvent action of CO_2 secreted by the roots.

There is much evidence at hand to show that either through a form of "growth-fusion" (4) or through the solvent action of plant-roots, when intimately in contact with the soil particle, plants have a definite feeding power, which acts independent of or increases the normal solvent action of the soil solution. In either case the CO_2 secretions of the roots are probably able to work at maximum efficiency. Irrespective of the exact manner in which plants feed it appears that they are able to control in a measure the nature of the ions absorbed and also it is quite possible that they exhibit considerable difference in the solvent action or feeding ability of the roots. We have in this

1. Marias, J.S. Soil Sci. 13, P. 355. 1922.
2. Tidmore, J.W. Soil Sci. Vol. 25, P. 13. 1928.
3. Metzger, W.H. Soil Sci. Vol. 25, P. 273. 1928.
4. Hoagland, D.R. Fourth Comm. Int. Cong. Soil Sci. Report. Soil Sci. Vol. 25, P. 48. 1928.

a possible answer to the query. "How can some plants take up more food than others?"

It may be that on soils poor in mineral matter strong feeding power would be detrimental to a plant. On a soil already acid enhanced acidity due to CO_2 secretion from the root may dissolve considerable toxic material. Definite proof of these hypotheses is lacking; nor can space be devoted to a full discussion of the merits and weaknessess of these conceptions. For our immediate concern it is only necessary to bear in mind that plants possibly do exhibit different solvent action on the soil and that carbonic acid may be the agent in the reaction.

Another factor on the plant side of the feeding process is the pH of the plant sap and its effect on nutrients and other material absorbed by a plant.

The Reaction of Plant Saps.

Plants differ considerably in the reactions of their saps, which are known to range from pH 3 - pH 7. The following analyses reveals that our heavy feeding legumes do tend to possess a reaction nearer neutral than the acid tolerate crops exhibit in their saps:

TABLE 4.

Sweet Clover	pH 7.0
Peas	6.7
Alfalfa	6.2
Soy Beans	6.0
Timothy	6.0
Red Clover	5.9
Wheat	5.8
Oats	5.6
Cow Peas	5.4
Lupine	5.3
Alsike	5.3
Corn	5.2
Buckwheat	5.0
Sorrel (Sheep)	3.0

Within the Leguminoseae we find cow peas and alsike two prominent exceptions to the group. Cow peas can be contrasted to Soy beans which perhaps are more sensitive to acidity; and alsike is here shown to differ to red clover, possessing an interval acidity of 5.3, four times as great in H-ion concentration as in red clover at pH 5.9.

The pH of the plant sap and the rate of protein synthesis are important considerations, according to Truog's (1) theory of plant feeding, which applies in particular to plant feeding on phosphate compounds. He maintains that difference in feeding power cannot be explained on the amount of CO_2 secreted by roots but only on the law of mass action and chemical equilibrium. Truog showed that only plants which utilize considerable calcium are able to secure sufficient phosphorus from rock phosphate.

1. Truog, E. Res. Bull 41. Univ. of Wis. 1916.

The reaction of tricalcium phosphate and carbonic acid illustrates the point:

$$Ca_3 (PO_4)_2 + 2 H_2 CO_3 \rightleftarrows Ca_2 H_2 (PO_4)_2 + Ca H_2 (CO_3)_2$$

For this reaction to continue one of the produces on the right must be removed. If it is to continue for any length of time the accumulation of the bicarbonate as well as the phosphate must be prevented, and this is why, Truog maintains, high protein plants can utilize the phosphate in rock phosphate. Most of the calcium is believed to act within the plant as a precipitant of organic acids, mainly oxalic,which are by-products of protein metabolism. Truog maintains that the use of Ca for this purpose offers an explanation of why most legumes growing on acid soils are benefitted by liming. Also he states, "Since red clover is lower in protein and calcium oxide than alfalfa and perhaps also grows slower, the explanation given also offers a possible explanation why red clover can withstand a higher degree of acidity than the former.

The internal acidity of plants must not be overlooked in this regard, for it is most certain that more buffering material must be required for a maintenance of the normal pH of the sap in alfalfa than in red clover. The sap of alsike would require less buffering than the two.

Another possible effect of the lower H-ion concentration within certain plants would be on the slightly soluble compounds such as iron, aluminum, manganese, silicon, which will be more readily precipitated within the plant. Latshaw (1),by his analytical work, has gathered data

1. Latshaw, W.L. and Miller, E.C. Jour.Agr.Res. Vol. XVII. No.11,1924.

which tends to substantiate this idea. He found that of 12.23 lbs. of aluminium in an acre crop of corn nearly 70% was in the roots, and of 9.91 lbs. of iron present, over 45% also occurred in the roots. 21% of the calcium occurred there, as well as 28% of the silicon which totalled 134.5 lbs. in the whole plant. Nitrogen, phosphorus, potassium, magnesium, sulphur, chlorine and manganese amounted to 5 - 15% in the roots. The greater concentration of aluminum and iron is emphasized by the fact that the roots constituted about 10% of the total crop weight.

The above data illustrate the point that a very great proportion of the slightly soluble soil elements taken up by plants settle in the roots. In view of the fact that the acidity of corn sap is placed at pH 5-2, one might expect equal or even greater precipitation of these elements in leguminous plants and plants of a more alkaline internal acidity.

Several other factors that should be mentioned are the area of root surface of a plant and the zone or horizon in which feeding takes place. Considerable variation does occur in the extent of the root systems of plants. In red clover culture the nature of the subsoil is extremely important. Since it depends to a considerable extent on its tap-root, the presence of an impervious subsoil, or one otherwise undesirable would severely check this plant. It has often been demonstrated that the plant food content of the several soil horizons varies considerably. Also the H-ion concentration of these varies; usually in humid regions, being less acid at lower horizons. A tap-root plant that must confine its activities to the top-soil will naturally have greater difficulty to survive. Bearing these points in mind alsike clover may be considered as better suited to humid soils than the deeply penetrating red clover plant.

The matter of permeability of the root-hair to different ions will not be considered to any length. While possibly, as Skeen (1) has suggested, permeability may be closely linked with the movement of Al and Fe in the plant, probably it has little to do with the movement of regular plant nutrients. In these elements, permeability at least does not appear as a limiting factor.

The influence of the rate of transpiration on the feeding power of plants has been shown by Curtis (2) to be of very little importance.

In concluding the above brief consideration of the feeding powers of plants it is well to repeat that plants as individuals possess different anabolic rates in which high protein species use a greater amount of plant foods than those which do not synthesize large amounts of protein. Nature has possibly endowed such plants with greater power to secure that food which they need. A good proportion of these plants are suited to soils which approach neutrality and on which they find a larger supply of plant foods. On many of the poor acid soils, which we find in humid climates, it may be impossible for the heavy feeding plants to secure their food requirements. Further they may not be able to ex-

1. Skeen, J.R. Soil Sci. Vol. 27, P. 77. 1929.
2. Curtis, O.F. Science (N.S.) 63:267-271. 1926.

tract sufficient calcium to buffer the organic acids formed and maintain the normal pH of their saps. And again, on such soils, if they exert an appreciable solvent action, solution of undesirable compounds may occur. Quickly growing species will probably find it more difficult to thrive, because of the low availability of plant foods in poor soils. Some of these speculations may in a large part explain why plants exhibit a greatly varying intake of soil material.

Although plants have been grouped as tolerant and sensitive to soil acidity it is well to remember that there is much evidence in the literature to suggest that soil acidity in itself is less injurious to plants than the soil changes which accompany changes of reaction.

<u>Summary of Chapter.</u>

In summarization of the discussion on the question of "Why Red Clovers tend to show failure more than do other crops," the point might be advanced that Red Clover as a member of the heavy feeding, generally lime loving family of Leguminoseae, is poorly adapted for many areas, not being well suited to the climatic conditions of dry areas or the soil conditions of humid climates. In contrast to it sweet clover and alfalfa on alkaline or neutral soils and alsike on acid soils are better adapted, with internal acidities approaching nearer the conditions of the soil upon which they are grown. Red Clover requires moist, mild conditions for growth but seldom finds the same except under acid soil conditions to which it is poorly adjusted.

The manner in which the rainfall is distributed throughout the year is important. A humid climate in which the summer months receive their share of precipitation is preferable to one in which there is an excessively heavy rainfall during the winter months, and little or no rain in the summer months. Red Clover may suffer considerably in the winter months in the latter type of climate as a result of flooding and saturated conditions. There may be considerable loss of plant food through leaching in the winter, and very dry conditions during parts of the growing season. Although precipitation in the Fraser Valley is above the average for the continent, the seasonal distribution is not as it might be desired.

Slipher (1) has illustrated the point of difference in soil reaction as it affects various crop plants by an analyses of seventeen liming experiments over a wide range of territory in the Eastern United States.

"Each kind of crop plant possesses an intrinsic sap acidity. Some, notably alfalfa, are characterized by a weak acidity while others are strongly acid. The purpose of liming a so-called acid soil is to reduce its reaction to a point milder than the internal acidity of the crop plant to be grown. ------ For no crop plant is it necessary to lime a soil to the point of neutrality. All crop plants grow successfully on the acid side of the neutral point. A wide difference in preference is noted, however. Alfalfa and sweet clover exhibit difficul-

1. Slipher, J.A. Ohio State Univ. Bull. 35, P. 47. 1927.

ty when the soil reaction falls below 6.5 pH. A drop of less than one pH below this level proves extremely injurious. Red Clover, on the other hand, possesses a lower range of tolerance, growing successfully at 5.75 pH but showing much distress at about 5 pH. Though the soy bean grows satisfactorily on soils with a pH of 4.5, it does best at 5.5 and 6 pH. As a group the cereal crops are more tolerant of acid than the legumes, although most of them do best on soils having pH values as high as 5.5 or 6."

After a discussion of the predominant causes of Clover Failure in the previous section of this thesis the opinion was expressed that red clover troubles were primarily due to undesirable conditions in the soil and secondarily to disease injury. The ravages of pathological organisms were deemed largely influenced by the health and vigor of the host plants and thus in a large measure were an indirect result of low productivity and poor fertility in the soil. By studying the data from experiment stations in various parts of the country, calcium, potassium and phosphorus compounds in the soil were shown to be important considerations in the problem.

Believing that the cause or causes of clover failure could, in all probability, be traced to the soil, the reason why red clover alone was susceptible appeared a very pertinent question. It is generally known that plants differ in sensitivity to soil acid conditions, and it was noted that red clover is used in mixtures and seeded with more acid-tolerant crops on acid soils of the humid regions. In an attempt to explain the differences in sensitivity to acidity recourse is made to the analyses of plant products and to the H-ion concentration of the plant sap. It is shown that the legumes as a group are what may be termed "heavy feeders" and with several note worthy exceptions show greater preference for soils nearer neutral than most other crops. Alsike, in contrast to red clover, has a far more acid sap and differs from red clover in a number of other features such as rate of growth, root system and to some extent in plant food content.

Even if we find it impossible to state definitely why Red Clover fails more readily than other crops do, we have now some indication of what we are searching for. While it has been worth while to consider several conceptions of the nature of plant feeding, we must not forget that experience of agricultural stations has shown that "clover failure" has been overcome generally with the aid of lime, phosphate fertilizers and manure. Why phosphoric acid should figure so prominently is hard to decide, especially in view of Truog's theory on the "Feeding Power of Plants" in which plants using much calcium are considered better able to take up phosphate than plants using little calcium. Red Clover, on this basis should be able to utilize phosphates of calcium very readily.

EXPERIMENTAL.

It undoubtedly appears from the foregoing discussions on the causes of Clover Failure that soil conditions are largely responsible for the occurrence of this trouble. It further appears logical that clover would be one of the first crops to show distress at these conditions because of its peculiar physiological requirements. In attempting to trace the trouble to its source the following causes appear most plausible:

1. A low amount of calcium, magnesium, potassium, or combinations of these in the soil.
2. Low available phosphatic acid.
3. High acidity.
4. Secondary effects of high acidity.
5. Combinations of these causes.

The author's investigations were based on these deductions and carried out as far as time permitted during the summer of 1931 and the academic period of 1931-32.

Field Trial - Peat Soil.

During the summer 1931 several experiments were conducted, one in the greenhouse, using Point Grey soil, the other on a Lulu Island peat which is underlaid with clay. The Point Grey experiments, because of the very distinct difference in soil type, will be treated together after considering the delta soils.

Although a peat soil possesses undesirable features for such a test, the trial was set out on this soil because no clover was being grown on it at all, the owner considering it a waste of money to seed clover. As far as other crops are concerned oats were doing well and potatoes were successfully grown on adjacent plots of similar soil type.

The details of this experiment follow:

Land - spring plowed; fertilized April 11, 1931; seeded April 18; harvested July 11, after a growing period of 84 days.

Plot Treatment	Yields			Average	Remarks
Check	47 lbs,	39 lbs,	89 lbs.	58 lbs.	Plants yellow.
Lime	56	63	110	76	Weedy.
Lime, Superphosphate and Muriate	137	190	176	168	Good clean stand.
Lime, Superphosphate, Potash of Magnesia, Nitrate of Soda and Sulphate of Ammonia	170	170	195	178	Good clean stand.

Plots were 1/99 acre and received treatments at the following rates:

Lime	2000 lbs. per acre		$K_2 SO_4$ $Mg SO_4$	400 lbs. per acre
Super.	450 " " "		$(NH_4)_2 SO_4$	75 " " "
Muriate	200 " " "		$Na NO_3$	75 " " "

The seed was drilled in by hand and the balance, to make 12 - 15 lbs. per acre, was broadcast. The spring of 1931 was very wet.

Interesting features of this experiment were, first, the low increases of the lime plots and the needy nature of the same, and, secondly, the high response of the phosphate - potash combination.

No yields were taken of the second crop. However, to the eye, the high increases did not last as well and probably there would be less difference between the plot yields. No explanation is offered of this except to submit the following observation: Due to rain or otherwise it seemed that the sharp lines between fertilized treatments did not show up distinctly but the good and poor plots merged one into the other. The foot borders between plots were not sufficient to absorb this gradation. By the time the second crop was developed this tendency had apparently spread much further.

The yields on the plots receiving lime, phosphate and potash were quite high. A nurse crop would have made considerable difference, but considering the fact that the hay crop would not be cut until the next season, the yields are considered very satisfactory. Nearly 9 tons green weight were harvested after growing 84 days.

Phosphate Analyses.

Following the Peat Soil experiment, in the month of September, trips were made through the Fraser Valley and a number of soil samples collected from fields which grew good red clover crops and from fields which did not. It was necessary in this to go largely on the word of the men interviewed and on the aftermath of the crop. For this reason accurate yields from fields visited were quite impossible but the samples were classified "good", "fair" and "poor" clover soils. These samples were taken to the laboratory, air dried and preserved for analytical work.

Because of the high yield of the phosphate-potash plots in the Peat Soil experiment interest was first directed to the phosphate content of these soils. The following table presents the results obtained in the total phosphate determinations:

TABLE 5.

Phosphate Analyses of Clover Soils.

No.	Soil	Apparent Density	Percent P_2O_5	Pounds P_2O_5 Per Acre
11	Good Top Soil	88.0	.16	3200
11S	" Sub "	96.7	.175	3845
1	Poor Top "	76.5	.183	3180
1S	" Sub "	93.5	.186	3956
16	U.B.C. Top Soil	123.1	.175*	3230
16S	" Sub "	124.4	.31**	4031
A	"Infertile" Top Soil	90.0	.14	2864
4	Poor Clay " "	90.0	.33	6750

* Based on 66% of Total Soil which passed through 10-mesh sieve.
** Based on 46% of Total Soil which passed through 10-mesh sieve.

Soils 11 and 11S- Clay loam and clay subsoil, bearing excellent clover stand.

" 1 " 1S - Peat with clay subsoil, very poor clover stand.

" 16 " 16S- Light sandy loam, clover poor. (U.B.C. soil).

" A - Clay loam, no crops of any kind being grown.

" 4 - Clay soil, general yields fair, clover very poor.

Considerable variation in total $P_2 O_5$ was found for the soils analysed, but no correlation whatever was found between $P_2 O_5$ content and clover productivity. The fertility of total $P_2 O_5$ analyses was realized and no further tests made.

Acidity of Clover Soils.

Following the phosphorus determinations the soil samples were tested for acidity. The pH of the soils was measured electrometrically using quinhydrone and a saturated calomel cell. A soil dilution of 1:2 was prepared, shaken one minute and then the mixture stood for twenty minutes and the pH of the supernatent liquid measured. In studying the pH of these soils, which is given in Table 6, it must be remembered that variations of 0.1 pH and 0.2 pH from the true pH can be expected due to the action of manganese on quinhydrone. That quinhydrone measurements of soils are slightly in error as a result of the oxidizing action of manganese dioxide has been shown by Heintze and Crowther (1).

1. Heintze, S.G. and Crowther, E.M. Trans. Second Comm. Int. Soc. Soil Sci. Budapest, 1927. A, 102.

TABLE 6.

pH of Clover Soils Determined on Air Dry Samples Using Quinhydrone.

			pH
A		Infertile	4.1
5		Poor	4.4
4		Poor	4.5
12		Fair to Good	4.8
1		Poor	4.9
1	sub.	Poor Subsoil	4.2
6		Fair	5.0
9		Good	5.0*
11		Good	5.0
11	sub.	Good Subsoil	5.5
10		Fair	5.1
7		Good	5.3*
8		Poor	5.3*
3		Good	5.3

* Based on 1st Season's Growth.

Because some errors are certain to be introduced through air-drying, use of quinhydrone, et cetera, and since the soil is known to fluctuate in degree of acidity the pH measurements in Table 6 are given to one decimal place only. Included in the soils studied is one infertile soil designated "A". This soil has not carried a crop to maturity for years. Growth starts satisfactorily in the spring and wilting and death of the crop follow upon the advent of hot weather. It is interesting to note that the "A" soil is very highly acid, far higher than other soils. The soils arrange themselves in general order of pH and clover productivity with the exception of Soils 12 and 8. In this regard mention of several facts will throw more light on these two soils. Soil 12 is taken from the same field as Soil 11 which is considered the best clover producing soil. It was included because the clover stand at that point was noticeably poorer but was still satisfactory. If it is on a subsoil with a pH approaching that of Soil 11 (sub) it may help explain how clovers thrive on its pH of 4.8.

Soils No. 8 and 9 are taken from the same field, the latter from the depressions and No. 8 from the ridges which rise only 1 or 2 feet but which are noticeably poorer. This selection is based on a first year's crop which was in oat stubble at the time of sampling. It is quite possible that some other factor such as moisture supply or subsoil is involved on some of these soils and so absolute agreement with pH cannot be expected.

Sample No. 1 is taken from the area where the Peat Soil experiment was conducted (see P.32). That it possesses a very acid subsoil is significant and very much in contrast to the good soil No. 11.

Exchangeable Calcium and Magnesium.

Soils A, 4, 1, 1(sub), 11, 11 (sub), 3 and 8 were selected out of the group of samples for a determination of Exchangeable Calcium and Magnesium. The earlier experiments and the historical study of clover troubles made it appear desirable to have an indication of the amounts of "available" mineral in the soil. It was thought that Base-exchange methods would be as satisfactory as any other in a determination of the supply of these elements in the soil, which can be used by the plant. In the time available it was not convenient to determine other bases as well.

The method of Kelley and Brown, as modified by Gedroiz* was employed in this work, using 25 gms. of soil and 1 litre of 1 N. NH_4 Cl. While the first two determinations were being carried out, one on a "good" soil and the other on a "poor" soil, the presence of an appreciable amount of relatively insoluble material in the extract from the poorer soil suggested the presence of aluminum and iron in the NH_4 Cl extract. Consequently a determination of Al_2 O_3 and Fe_2 O_3 in the exchange material was made at a later date. In this extraction a 1:5 ratio of soil to NH_4 Cl extract was used. This proportion of soil to solution was used so that a comparison with the work of Burgess and Pember (1) could be made.

Al_2 O_3 and Fe_2 O_3 were weighed together and the Fe_2 O_3 was determined after reduction with zinc. The actual amount of iron present was very small and so in Table 7 the oxides of iron and aluminum are reported as Al_2 O_3 only.

* See Page, H.J. Jour. Agr. Sci. 1924. 14, 133.
(1) Burgess, P.S. and Pember, F.R. Bull. 194, Rhode Isl.State Coll. 1923.

TABLE 7.

Exchangeable Ca, Mg and Al* in Clover Soils of Varying Degrees of Fertility.

Soil	pH	Clover Producing power.	Millegram equivalents				Al_2O_3 in NH_4Cl extract
			Ca	Mg	Al	Ca + Mg	p.p.m.
11 sub	5.5	good	4.16	9.79	0.65	13.95	12.0
11	5.0	"	6.37	7.29	1.23	13.66	22.2
3	5.3	"	7.79	3.94	1.81	11.71	33.8
8	5.3	poor	4.45	4.50	1.49	8.95	26.8
4	4.5	"	3.06	2.84	8.75	5.90	157.6
1	4.9	"	11.34	Trace	3.33	11.34	60.0
1 sub	4.2	"	2.69	Trace	16.70	2.69	300.6
A	4.1	infertile	2.40	1.83	20.96	4.23	377.4

* Al + Trace Fe

The results of the Base Exchange analyses show us that there is very good agreement between pH of the clover soils and their content of exchangeable calcium and magnesium. This is to be expected since it is believed that the content of exchangeable Ca and Mg (and other bases) determines in a large part the pH of a soil. That the Base content and not the pH of the nutrient medium is the more critical factor controlling growth is debateable but appears probable in view of work by Pierre (1).

Soils 1 and 8 appear to differ from the other soils in some respects. No. 1 and its subsoil gave only a trace of magnesium. The behavior of Soil No. 8 can be accounted for somewhat when it is seen

(1) Pierre, W.H. Soil Sci. 31. P. 205. 1931.

that, for the amount of Ca and Mg found, it is too alkaline to be in harmony with the situation in other soils.

FIGURE 1.

Millegram Equivalents* of Exchangeable Calcium and Magnesium in Soils of Different Degrees of Acidity.

* Millegram equivalent = equivalent weight in millegrams.

Judging by Figure 1. a pH of 4.8 or 4.9 would be in closer keeping with the base content. This is further evidence on the opinion that the pH itself is not the most important factor in determining the degree of fertility of the soil.

Aluminum.

The data in respect to aluminum immediately commands attention. Determinations of the amount of aluminum and iron extractable with "neutral" salts have been made by a number of men. Kelley and Brown (1) report "each of the acid soils studied by them contain more or less replaceable aluminum and manganese and two of them replaceable iron. When expressed on the basis of chemical equivalents the trivalent bases were found to comprise a considerable percentage of the total."

Magistad (2) found that "experiments with neutral and acid solutions of iron and aluminum salts on artificial zeolites showed that the replaceable bases previously present were released." He further discovered that the Fe and Al absorbed could not again be replaced and also "the decrease in base-exchange capacity of zeolites and soils is a function of the concentration of ferric iron or aluminum salt solutions used." In conclusion he states, "if the property of base-exchange is to be considered a factor in plant feeding, destruction of base-exchange capacity in soils by aluminum containing salts or other means may result in serious consequences."

Considerable evidence is at hand which substantiates the idea that aluminum even in small amounts is highly toxic to plants. It is also apparent that plants differ in their resistance to soluble aluminum. Burgess and Pember (3) have carefully studied the effect of "active"

(1) Kelley, and Brown, Replaceable Bases in Soils. Sept. 1924. Tech. Paper No. 15. P. 18.
(2) Magistad, Tech. Bull. 18. U. of Virginia. P.462. 1928.
(3) Burgess, P.S. and Pember, F.R. Bull. 194. Agr. Exp. Sta. Kingston, R.I. U.S.A. P. 31.

aluminum on crops growing on acid soils. By "active" aluminum is meant that which is soluble in 0.5 N. acetic acid. They find that "in the same soil type, a fairly close correlation existed between the growth of sensitive crop plants, the amounts of active aluminum present in the soil, and the H-ion concentration of the soil." Based on considerable investigation these workers present the following tentative classification of the comparative resistances of a number of crop plants to soil acidity and active aluminum.

TABLE 8.

A Tentative Classification of the Comparative Resistances of Certain Plants to Soil Acidity and Active Aluminum.[1]

pH limits	Low above 6	Medium 6 to 5.3	High below 5.3
"Lime Requirement" (Jones)	below 1500 lbs. Ca O	1500-3000 lbs. Ca O	above 3000 lbs. Ca O
Active Alumina	Below 300 p.p.m.	300-500 p.p.m.	above 500 p.p.m.
	Asparagus	Barley	Oats
	Onions **	Rape	Buckwheat
	Lettuce **	Cabbage	Pumpkins
	Spinach **	Red Clover	Red Top
	Parsnips	Sweet Clover	Vetch (summer)
	Leeks **	Dandelions	Wheat
	Alfalfa		Alsike clover
	Beets (Sugar)		Rye
	Mangels		Carrots
			Potatoes
			Corn
			Millet
			Turnips

(1) Bull. 194. Agr. Exp. Sta. Rhode Island College. P.31.
** Very low resistance, extremely sensitive to aluminum.

In Burgess and Pember's classification Red Clover is placed as medium sensitive, preferring a pH of 6 to 5.3. Under "high resistance" crops we see most of our common Fraser Valley crop plants placed in a class tolerant to considerable active aluminum and acidity below pH 5.3, which is not highly acid for Fraser Valley soils.

By the addition of lime or phosphate or both, these workers were able to improve yields. Applications of acid phosphate far in excess of food requirements gave increased yields. Even a sensitive crop like lettuce grew well at a pH below 4.5 when sufficient phosphate was present.

In conclusion of their work, Burgess and Pember state:

"The plants which received large amounts of acid phosphate grew well although they contained approximately the same percentages of aluminum as the checks. However, they carried from three to five times as much phosphorus. It thus appears that acid phosphate renders soluble aluminum salts non-toxic largely by counteracting their evil effects within the plants themselves after they have been absorbed.

The highest percentages of aluminum were found in the roots, considerable in the leaves, a little in the stems and none in the grain. Barley and lettuce were the crops analysed."

Gilbert and Pember (1) report further evidence indicating that in soil cultures "active" aluminum has a greater inhibitory effect on the growth of lettuce and barley plants than acidity.

In view of the afore-mentioned studies by Kelley and Brown, Magistad, Burgess and Pember, the writer became keenly interested in the amounts of aluminum extracted from his clover soils, especially in view of the great difference in quantity determined. These amounts of "exchangeable" aluminum are presented graphically in Figure 2.

(1) Gilbert, B.E. and Pember, F.R. Soil Sci. 31, P. 273. 1931.

FIGURE 2.

The regularity of this curve makes it appear as if solubility is concerned. The writer felt that caution should be employed before interpreting the aluminum as "exchangeable" material as others have done. Consequently the matter was investigated for the purpose of determining if the aluminum present could be traceable to normal solvent action. However one difficulty in accepting this explanation appeared when it was noted that the amount of aluminum in solution was far above saturation for $Al_2 O_3$ in water at the pH's of the various soils. Magistad (1)

(1) Magistad, O.C. Soil Sci. Vol. XX, No.3. Sept. 1925. P. 193.

has presented a solubility curve for $Al_2 O_3$ in water which he maintains is nearly identical with the solubility curve for alumina in the soil solution. The work of Joffe and McLean (1) has shown that the $Al_2 O_3$ in solution however is not always identical with the solubility curve of $Al_2 O_3$ in water, but is influenced to some extent by the presence of anions other than (OH) ions.

It appeared that the pH of the soils must have shifted upon the addition of $NH_4 Cl$ because of the high concentration of $Al_2 O_3$. The only other possibility was that the aluminum was present in union with organic anions on which condition ionization is only slight. But this was considered improbable.

Consequently the pH of the soil -- $NH_4 Cl$ solution system was again measured. These measurements are presented in Table 9 along with an estimation of the increase in concentration of H-ions due to the action of the $NH_4 Cl$ solution on the soil.

TABLE 9.

Soil	Fertility	Soil pH	pH of $NH_4 Cl$ extract	Increase in H-ion Conc. x 10-5
11 (sub)	Good	5.5	4.7	2.0
11	"	5.0	4.5	2.2
3	"	5.3	4.5	2.7
8	Poor	5.3	4.3	4.5
4	"	4.5	4.1	5.1
1	"	4.9	4.1	8.0
1 (sub)	"	4.2	3.8	9.4
A	Infertile	4.1	3.9	4.6

(1) Joffe, J.S. and McLean, H.C. Proc. and Papers. 1st Int.Cong.Soil Sci. P. 230. 1928.

It is found that the addition of five parts of N. NH_4 Cl solution increases the pH considerably and that the quantities of $Al_2 O_3$ found in the soils, when plotted at this new pH, agree very well with the solubility curve of $Al_2 O_3$ in water.

The source of the liberated H-ions is uncertain but in all probability they are mostly freed in the cation-exchange of H^+ ions for NH_4^+ ions. A large proportion of the H^+ ions probably do not go into solution in ionic form, as a result of buffering action in the less acid soils. However, the poorer, more acid soils would, as a rule, be in a comparatively unsaturated state and would free larger amounts of the cation-hydrogen when treated with NH_4 Cl solution. In fact we find from Table 9 that the amount of H-ions liberated into the supernatent NH_4 Cl solution was roughly twice as great in all the poor soils when compared to the good soils. In this respect Soil No. 8, which has acted queer in most determinations, is found to give high increase in H-ion concentration along with the poor soils.

As suggested above, the amount of H-ion liberated by the NH4 Cl solution cannot be determined quantitatively by the increase in H-ion concentration due to secondary reactions of a buffering nature. Therefore these data must be considered as indicative only of certain tendencies. However the increased acidity of the soil NH_4 Cl system would tend to dissolve some insoluble soil minerals and tend to introduce an error in the amounts of exchangeable calcium and magnesium found.

In Figure 3 the solubility curve is plotted (from Magistad) and the amounts of Al_2O_3 at the pH of the NH_4Cl extract is indicated. It appears from this that the Al_2O_3 is brought into solution due to secondary effects of the reaction which is considerably increased in the poorer soils. In studying Figure 3, it must be remembered that soil pH determinations have been interpreted to the nearest 0.1 pH. This fact will help explain the lack of agreement that does exist.

FIGURE 3.

Solubility of Aluminum in the Soil Solution.

If the amount of alumina extracted with N. NH_4 Cl is influenced as it appears that it may be, by the liberation of exchange acidity, data gathered in this way could not be expected to correlate with crop response in every case. The amount of alumina would indicate in a manner the degree of unsaturation and the buffering power that a soil possesses. So any correlation found between plant growth and exchange aluminum may be due entirely to a more direct correlation between the degree of base saturation or the total exchange calcium (and other bases) and crop response.

Aluminum toxicity on certain soils is an established fact. The solubility of aluminum is influenced by the pH of the solution and the nature of anions present. Therefore, in studying the degree of aluminum toxicity the pH of the soil is of major importance. Another factor, which may have considerable effect on the toxicity of aluminum is the solvent action of plant roots.

Since Magistad found the curve showing the amount of aluminum present in the soil solution to be nearly identical with the curve showing the solubility of aluminum sulphate in water at various pH values, it seems safe to use the solubility curve of Al_2O_3 in water as a guide to the Al_2O_3 content in the soil solution. Figure 4 presents the solubility curve for Al_2O_3 in water. The pH of the author's clover soils is indicated on this curve.

FIGURE 4.

Pierre (1), and Joffe and McLean (2) have found that the $Al_2 O_3$ content of the soil solution does not vary quite as uniformly with changes of pH as was suggested by Magistad. Joffe and McLean found the kinds of anions present to have marked effect. These workers found aluminum to be soluble at considerably lower degrees of acidity as the nitrate or chloride than as the phosphate or sulphate. Pierre found, especially up to 1 and 2 p.p.m., that considerable variation occurred to what one would expect from the pH of the soil. However none of the soils above pH 5 gave as high as 1.0 p.p.m. aluminum. When a pH as low as 4.7 was present a considerably greater amount of aluminum was found.

(1) Pierre, W.H. Soil Sci. 31. P. 183. 1931.
(2) Joffe, J.S. and McLean, H.C. Soil Sci. 26. P. 47. 1928.

Magistad's work has shown that below pH 4.7 aluminum becomes appreciably soluble and increases in solubility very quickly from that point as acidity is increased. In the author's clover soils, three soils and 1 subsoil gave a pH reading below 4.7. In the case of the infertile soil a concentration of $Al_2 O_3$ of over 50 p.p.m. is quite possible. There would in any event be a high concentration of $Al_2 O_3$ in solution at such a low pH. In the peat soil, upon which the peat soil field trial had been conducted, the effect of aluminum would not be very great. The subsoil, however, could contain over 25 p.p.m. of $Al_2 O_3$ in the soil solution, judging by Figure 4. The other two soils which have given pH values below 4.7 are definitely poor clover producers.

Since,as above mentioned, it is virtually proven that plants secrete appreciable amounts of CO_2 to raise the pH in the zone of intimate contact between root and soil, the possible effect of this increased H-ion concentration on the soil warrants attention. It is more than possible that soils, even up to pH 5.0 or thereabouts, may suffer due to the pH in the immediate vicinity of the roots falling below 4.7.

The aluminum content of the soil solution is certain to reach a point at which it will tend to check plant growth, particularly in some species, when a pH as low as 4.7 occurs.

A saturated solution of CO_2 in distilled water possesses a pH of about 4.1 or 4.2. With only a trace of base present such as $Ca H_2 (CO_3)_2$ or a magnesium salt the pH cannot be reduced nearly as far. The writer found that pH 5.6 was the acid limit even in a very dilute solution of $Mg CO_3$. It would require very little of a highly ionized bicarbonate salt to materially reduce the ionization of carbonic acid and in that way buffer the solution considerably.

Time did not permit a thorough investigation of the buffering power of these soils against saturation with CO_2. However the problem appeared sufficiently interesting to prompt even a superficial investigation. Consequently an extract of the various clover soils was made to determine the action of CO_2 in lowering the pH of the extracts. In preparing these a 1:2 dilution was made with the air-dry soil, and after shaking and standing twenty minutes the supernatent liquid was filtered and the pH determined colorimetrically. The measurements obtained were:

TABLE 10.

pH of CO_2 - Saturated Soil Extracts.

No.	Clover Producing Power	Original pH	pH of CO_2 saturated extract.
A	Infertile	4.1	4.1
A (sub)	"	-	4.1
5	Poor	4.4	4.3
4	"	4.5	4.3
12	Good	4.8	4.45
1	Poor	4.9	4.3
1 (sub)	"	4.2	4.25
6	Fair	5.0	4.3
9	Good *	5.0	4.4
11	Very good	5.0	4.5
11 (sub)	" "	5.5	4.7
8	Poor *	5.1	4.4
10	Fair	5.1	4.45
7	Good *	5.3	4.25
3	"	5.3	4.3

* = From same farm based on 1st year growth of clover.

Considerable buffering effect is exhibited by several of the soils. The buffering effect within the soil itself would be greater because the additional mineral would be dissolved by the action of the acid, and so it is improbable that as high acidities as are here indicated would prevail even in close contact with the root hair. This phase of the problem warrants attention. At the present time insufficient data is available on the matter to draw any conclusions and information would be very difficult to obtain.

Microflora in Clover Soils.

As a final consideration, in March 1932, the author returned to several of the fields to obtain samples of soil for a determination of the microfloral population in the various soils that had been used in the laboratory. The soils were still rather wet and cold at that time of the year. The counts obtained from the clover soils are given here:

TABLE 11.

No.*	Soil	Fungi	Actinomyces	Bacteria	Total
A	Infertile	68,000	170,000	110,000	348,000
1S	Poor Sub	4,500	160,000	310,000	474,500
1	" Top	102,000	1,480,000	4,000,000	5,582,000
4	" "	88,000	2,800,000	3,600,000	6,488,000
3	Good "	106,000	3,100,000	6,300,000	9,506,000
11	" "	81,000	2,000,000	3,300,000	5,381,000

* See Table 6.

In the counts of soil organisms as given above very little can be said except in regard to the Infertile soil. This soil has shown itself to be inferior throughout the entire study and this inferiority is reflected in the microfloral population. It is extremely low in the number of bacteria, containing only about one-third the number occuring in the subsoil. The subsoil is considered to be a poor one and to exceed a top soil in number of microörganisms reflects very strongly on the low quality of the top-soil. In regard to the Infertile "A" soil, it will be of interest to note that field observation has shown the decomposing power of the soil to be very low. On one occasion the soil was treated with horse manure and then plowed under. In the next year, the operator of the farm reports, the dung had shown very little decomposition when plowed up again. Root fibres in the soil also indicate very little decomposing action by soil organisms.

Tests on Upland Soils at the University.

Up to this point all studies reported have been conducted on delta soils in the Fraser Valley. They have been clays, silts and peat soils. These now follow the results of several experiments conducted on the upland, sandy, gravelly soils of the University Farm at Point Grey.

Because of the decided difference in soil conditions the following one reported separately from the investigations on the heavier soil types.

The Greenhouse Test.

An experiment was attempted in the greenhouse, using two soils, one from a field that had been cropped for about fourteen years and another soil that, although cleared, had not previously been cropped. These soils were taken from the University Farm at Point Grey. The cropped soil is reported to be giving poorer clover yields than had been harvested ten years previous. The soil itself is upland coast type in texture, a sandy, gravelly loam.

On February 3, 1931, the cropped soil was transported to the greenhouse, thoroughly mixed, passed through a coarse sieve and potted. The uncropped soil was treated similarly and prepared for fertilizing and seeding on February 22.

The treatments were limited by the available greenhouse space, but were arranged to test the effect of calcium as food; lime, potassium, magnesium and phosphoric acid singly and in combinations.

The fertilizer was added several days before seeding by spreading over the pots and stirring into the upper part of the soil. The seed itself was produced in British Columbia under climatic conditions which are more severe than the average. Inoculation was assured by watering just after seeding with a suspension of a Rhizobium strain, which was known to be good, from the standpoint of its symbiotic value to the plant. The rate of watering was uniform for all pots.

After being seeded on March 14, the plants were thinned to equal numbers and allowed to grow 122 days before harvesting. A second cutting was made 51 days later.

Yields were recorded to an accuracy of one-quarter ounce and are here presented on a relative basis with the check plots as 100.

TABLE 12.

Relative Yields of Red Clover in Greenhouse Pot-test on Point Grey Soils.

Treatment *	Old Soil		New Soil	
	1st Cut	2nd Cut	1st Cut	2nd Cut
Check	100	100	100	100
Lime (hydrated)	107	112	100	81
Magnesium Sulphate	107	111	113	81
Superphosphate	117	111	107	91
Potash	102	105	100	89
Treble Phosphate	116	117	150	75
" + Potash	130	112	120	78
" + Lime	120	101	127	109
" + Magnesia	116	118	143	91
" + Potash and Lime	105	120	133	172
" + " + Magnesia	127	120	133	100
" + " + " + Lime	Injured	Injured	197	106

* Rates of Application = Lime - 1400 lbs. Ca OH per acre.
Treble Phosphate - 142 lbs. per acre
Super. " - 350 " " "
$K_2 SO_4$ - 150 " " "
$Ca SO_4$ - 300 " " "
$Mg SO_4$ - 430 " " "

In looking over the pot yields it must first be admitted that yields are very irregular. However, from the point of view of earlier discussions in this thesis several observations are in order. Lime has given only slight increases. Potash alone has done very little.

The phosphate fertilizers have shown the only increases that are at all consistent or appreciable. It appears that, in the second cutting, there is greater uniformity of yield between treatments than in the first.

In this regard a salient observation was recorded after less than one month's growth. With scarcely an exception the phosphate pots in both new and old soil grew sturdier and more rapidly than all other pots. From the seedling stage marked differences slowly disappeared until very little distinction in growth could be detected with the eye toward the end of the experiment.

The explanation for the phosphate treated pots failing to maintain their early advantage can scarcely be accounted for. It was thought at the time that perchance the soils were low in available phosphate and that due to the very desirable, although artificial moisture and temperature conditions, biological and chemical activity had overcome the state of deficiency in the non-phosphate treated pots. It may even be suggested that the feeding rootlets soon reached below the layer of soil in which the fertilizer had been applied and that the value of the treatment to the plant was not as great in the later stages of growth.

In substantiation of the evidence obtained in the greenhouse test, the author has access to the results of three other experiments on Point Grey soil which are now submitted briefly:

<u>Lime Trial on Clover.</u>

The first of these experiments conducted from 1925 - 1929 on the University Farm, was known as the Sulphur Experiment (1). In part of this

(1) Peden, E.E. Unpublished thesis. Univ. of B.C. 1930.

field trial red clover was grown on plots that received at the outset 100 lbs. Nitrate of Soda, 80 lbs. Muriate of Potash, 200 lbs. Superphosphate and also 10 tons of Stable Manure, and on half of which lime was applied while the other plots remained as checks. The lime, applied in three different years, totalled 3440 pounds.

The yields harvested indicated each of the five years that clover did not do better on this soil when lime was added to an application of complete fertilizer. The yield over the five year period on the limed plots totalled 92.5% of the yields on lime-free plots. In the second year the maximum yield of 3.6 tons per acre was obtained.

Although the degree of acidity has not been recorded on these plots, it is known that they are not highly acid for coast soils. The lighter upland soils as a rule have a higher pH than the alluvial soils of the delta country. Several years later the author measured the pH in another part of the field and found a pH of 5.6 and a measurement for the subsoil showing pH 6.0. According to the data studied earlier in this thesis the above pH's would not be considered too acid for red clover.

Greenhouse Test on Kale and Wheat.

The experiment (1) now being considered was conducted in the greenhouse at the University of British Columbia and yielded interesting data which can be considered here in spite of the fact that clover was not being used.

(1) Peden, E.E. See previous page.

Using Wheat and Kale in pot trials the following responses were obtained with lime and lime plus phosphoric acid:

Percent Yields Compared to Checks in Greenhouse Test on Wheat and Kale.

Treatment	Wheat		Kale	
	Tops	Roots	Tops	Roots
	%	%	%	%
Nothing	100	100	100	100
Lime	102	101	155	130
Treble Phosphoric acid	120	154	382	354

This experiment ran for 115 days during the winter months, growth was relatively slow, in spite of the use of artificial lighting. The soil used was from the University Farm at Point Grey.

Confirmation of the reliability of yields obtained in the previously mentioned experiments on Point Grey soils is indicated by the low response to lime and high response to phosphoric acid.

It is very interesting to note that kale, a heavy feeding plant, responded more to lime than did wheat,and upon addition of phosphoric acid gave an increase of over 250%. Here again phosphoric acid stands out as the fertilizing element that gave by far the greatest increases.

Fertilizing Trial on Grass and Clover.

A further experiment on Point Grey soil is reported by Brown (1).

(1) Brown, W.C. A Study of the Effects of Test on a General Clover Grass Mixture in a Seven-year Experiment on Sandy Gravelly Soil." April 1928. Univ. of B.C. Thesis.

Liming did not increase yields in a grass and clover mixture to any appreciable extent; nor was the percentage of clover in the ley increased generally with the use of lime. Phosphate gave some increase in yields especially in the first years of the experiment but the percent clover on phosphate plots was consistently low. Potash did better than phosphate. A combination of phosphate and potash gave the highest yields throughout the experiment and proved to be the only treatment which produced a percentage of clover exceeding that of the checks.

DISCUSSION.

Common Red Clover has shown a tendency to do better on virgin soils than on comparatively old ones. Even when other crops seem to thrive well, Red Clover finds difficulty in maintaining itself after a period of years. Agriculturists throughout the civilized world appear to have noted the same behavior of Red Clover. In parts of British Columbia there is a definite Red Clover Problem, on many soils at least. This thesis is based on a preliminary investigation of the trouble, in which an attempt has been made to determine the most important causes of Red Clover Failure in this territory, and when this has not been possible to secure some indications of where the trouble lies, as basis for future work on the clover problem.

By a study of the causes of clover failure that have been advanced by Research Stations and that have become apparent through field practice, it has been shown that soil factors are the most probable causes of the phenomenon. The view was also expressed that disease injury is also important, but takes its toll largely from clover stands that have already been "physiologically sick" as a result of poor soil conditions.

More has been accomplished in alleviating clover failure with lime and phosphoric acid than with any other treatments. Clover seems to respond more to these than do most other crops.

Since failure is associated with red clover more than with other crop plants, time has been spent in considering why red clover should exhibit different behavior to other crops. The plant seems to possess requirements of an alkaline or slightly acid soil, whereas it prefers the humidity of a climate in which soil acidity is predominant. Red clover has been classified as an acid sensitive crop, but is generally grown in a mixture which includes species that are tolerant to acid soil conditions.

Cognizance is taken of the fact that many soil students believe soil acidity is injurious to crop plants due to soil conditions that accompany acidity and not to the H-ion concentration itself.

Red clover is one of the group of plants called "heavy feeders." It removes more calcium and magnesium than most other plants, including alsike clover. It is thought that lack of available mineral is a reason why red clover does more poorly on acid soils than does alsike clover. The reactions of the plant saps appears to be another reason for the different behavior of alsike and red clovers. Red clover has a relatively alkaline sap. It is also faster growing and thus requires more food in a given time.

The effect of the feeding roots is considered, but in view of insufficient data being available few conclusions are drawn. The effect of root secretions on the solubility of toxins is also considered.

Experiments are cited which show that in British Columbia phosphoric acid fertilizers appear to do more than any other fertilizer, including lime, to increase clover growth. Even on a peat soil which gave a pH measurement of 4.9 the use of treble phosphate and lime when added gave an increase of nearly 200% and a cleaner stand of clover than when lime alone was added. As compared to the check plots lime gave only a slight increase. Other tests at Point Grey showed that phosphate or phosphate and potash produced increases, when lime did comparatively little.

Soil acidity tests and determinations of Exchangeable Calcium and Magnesium showed that fair correlation existed between the growth of clover and both the degree of acidity and the amount of exchangeable bases. Only a few subsoils were worked on, but these indicated that the subsoil was a very important consideration, differing considerably from the top soil at times.

Attention was given to the aluminum in the Base-exchange extract and in the soil solution as it is effected by the degree of acidity of the soil. Reference to works in which aluminum toxicity was noted has been made. Even crops very sensitive to acidity or soluble aluminum have been grown on quite acid soils with the aid of phosphoric acid or lime. Applications of superphosphate far heavier than that required for food have shown that phosphate serves some other purpose as well as for plant food. There seems to be a parallel here with the response to applications of phosphoric acid made by red clover. The difference in response to phosphoric acid made by different species was shown in a greenhouse test. In it wheat responded far less to phosphoric acid than did kale, a heavy feeding plant.

On the whole, the soils studied correlated well with soil acidity and also exchangeable bases, but did not correlate at all with total phosphorus. The results agreed with the findings of research stations which show that lime and phosphoric acid and potash were correctives for clover failure. Of these, phosphoric acid has generally proven to be the best fertilizing agent. On this very point, it appears, the whole problem hinges. It is strange that phosphoric acid should do so much for red clover when analyses show that red clover contains no more, or very little more, phosphoric acid than other crops. In mineral content, however, it is outstandingly greater in its content than most other crops.

Another interesting phase of phosphoric acid fertilization is that the effect of light applications does not appear to be lasting. Early responses to phosphoric acid in a crop tend to disappear.

A study of the effect of phosphoric acid on the clover plant may throw considerable light on this problem. It may show that the form of phosphate taken up by the plant is important. As the acidity is also a factor in determining the proportions of $Al\ PO_4$, $Fe\ PO_4$, $Ca_3(PO_4)_2$, $Ca\ H\ PO_4$, and $Ca\ H_4\ (PO_4)_2$, $Mg_3\ (PO_4)_2$, et cetera, found in the soil, there may be some explanation forthcoming of the relationship of liming, phosphate fertilization and the effect of toxic soil minerals.

SUMMARY.

A rather extensive consideration of Red Clover Failure is made. The work done is more extensive than intensive, but indicates wherein the causes of clover failure lie.

The problem in British Columbia seems to be similar to that occurring elsewhere.

Correlations between clover producing power of soils and the acidity as well as with the exchangeable Ca and Mg were found.

There was no agreement between total $P_2 O_5$ content and growth of clover.

The effect of phosphoric acid fertilizers on clover is discussed but no conclusions are drawn for want of data. This phase of the problem warrants investigation in view of the fact that clovers respond better to phosphoric acid than to any other treatments that have been tried.

The effect of subsoil should also be investigated.

An infertile soil studied showed excessive acidity, low exchangeable Ca and Mg but high $Al_2 O_3$ in the Base-exchange extract.

On the infertile soil the microörganic population was unusually low.