1949

The elimination of white clover (Trifolium repens) from turf with particular reference to nitrogen levels.

Geoffrey S. Cornish
University of Massachusetts Amherst

THE ELIMINATION OF WHITE CLOVER

(TRIFOLIUM REPENS)

FROM TURF WITH PARTICULAR REFERENCE TO NITROGEN LEVELS

CORNISH

THE ELIMINATION OF WHITE CLOVER (TRIFOLIUM REPENS) FROM TURF WITH PARTICULAR REFERENCE TO NITROGEN LEVELS

by

Geoffrey S. Cornish

Thesis submitted for degree of Master of Science

Department of Agronomy

University of Massachusetts

Amherst, Massachusetts

1949

TABLE OF CONTENTS

Page

INTRODUCTION 1

REVIEW OF LITERATURE 3

General Factors Affecting the Growth of White Clover 3

Soil Preference
Association of White Clover and Grass
White Clover Years
Climate and Weather Conditions
Winter Injury
Diseases and Insect Pests

Effect of Management and Fertilizer Practices 7

Physiological Considerations of Effect of Applied Nitrogen on White Clover Content of a Mixed Clover-Grass Stand 12

Effect on Symbiotic Fixation
Effect on Light Relations
Increase in Carbon Dioxide Content
Nitrogen Absorption and Cation-Anion Relationship
Blackman's Experiments and Hypotheses

EXPERIMENTAL 24

Effect of Nitrogenous Material on the White Clover Content of a Lawn Area 25

Effect of a Single Application of a Nitrogenous Material 28

Effect of Three Applications of Nitrogenous Materials at Two Week Intervals 32

CONCLUSIONS AND RECOMMENDATIONS 35

SUMMARY 37

LITERATURE CITED 50

INTRODUCTION

Although white clover (Trifolium repens) is a desirable component of some fine turf areas, it is an obnoxious weed on others, particularly on sports areas where trueness of texture is required.

An outstanding example of its obnoxiousness is on golf putting greens where it destroys the trueness which is otherwise offered by an even sward of close-clipped, fine-textured, turf-forming grasses. Moreover, on golf fairways it does not provide as good a lie for the ball as pure grass stands.

Its presence in home lawns is a matter of taste, but it is sometimes considered to present a ragged appearance in contrast to the grass blades, and its blossoms are unsightly. In children's playgrounds it has a staining effect on clothing and on tennis courts it interferes with the bounce of the ball.

On lawn areas where it is not desired, it frequently volunteers in abundance even though it has not been seeded, and the problem of its elimination exists. Each year considerable money is used attempting to destroy it, or if knowledge and money are not available, its presence is accepted with a consequent deterioration in the quality of the turf.

Unfortunately, the value of herbicides to eradicate white clover is limited. The selective herbicide 2,4-D, although sometimes effective against this weed, has a tendency to destroy various bent grasses which constitute the basic species of many turf areas. The type of herbicide which was used prior to 2,4-D and which relied on a "burning" effect, usually injured the basic grasses when applied at rates sufficiently high to destroy the clover.

This thesis reviews literature concerning the effect of management and fertilizer practices on the grass-clover ratio of turf. Particular attention is made to the depressive effect of nitrogen on white clover and to the physiological considerations that have been put forward to explain this phenomenon.

With these considerations in mind, the problem of type and rate of nitrogen fertilizers most effective in eradicating clover was investigated. Data and conclusions arising from the experiments are presented.

REVIEW OF LITERATURE

General Factors Affecting the Growth of White Clover

According to Hollowell (21) and Dodd (15), the species Trifolium repens has an extremely wide range of adaptation. The natural variation in white clover strains had considerable to do with the wide natural distribution of this species and its persistence under a fairly wide range of environmental conditions.

Soil Preference

Hollowell (21) stated that white clover is the most tolerant of any of the clovers of adverse soil conditions. The old saying, "the harder and firmer the soil, the better for the clover", is borne out in part by his statement to the effect that clay and loam soil, provided they remain sufficiently moist to keep the plant alive, are better suited to white clover than sandy soil, probably because of the droughty nature and lower mineral content of the latter.

Dodd (15) found that white clover is not generally present in abundance in shallow upland soil types or on heavy types that dry out quickly. He observed that it is very partial to those types having an ability to maintain a good moisture content and has frequently been observed in abundance on lands too wet for many other crops. He stated that it is much more tolerant of an excess of water than a deficiency. Dodd concluded that a pH of 5.8 and a medium content of active calcium represent the economic minimum for the production of white clover in Ohio, with a pH above 6.0 believed to be more desirable.

Garner and Damon (18) in reference to clover in fine turf, observed in their plots that white clover volunteered most freely in soils having a slightly acid reaction.

Cooper, Wilson and Barron (14) concluded that quantity and quality of cations and anions in soil complexes may be of more importance than pH in determining a soil's suitability for growth of certain plants. In regard to white clover, they stated that it had a high fertility requirement and would grow equally well on soils of medium pH levels if they were well provided with certain elements.

<u>Association of White Clover and Grass</u>

Beaumont (5) observed that clover encroaches on pasture grasses under certain fertilizer treatments without resort to seeding.

Dodd (15) found that white clover suffers much more in both summer and winter when grown alone than when grown in association with grass. He noted that it occupied more area when grown with an open, coarse grass than with a tight, turf-forming grass.

Brown (12) noted that clover was much less prevalent with turf-forming grasses such as bluegrasses and bents, than with species having more open stands.

Hollowell (21) stated that white clover, as a profusely seeding perennial legume and a spreader by creeping stolons, normally grows in association with grass. Even when clover is seeded alone, grass soon encroaches and makes an excellent growth, indicating that the presence of clover creates an ideal condition for grass growth.

Ahlgren and Aamodt (1) made a series of field observations indicating that a number of species interactions occurred which could not be accounted for on the basis of differential response to light, temperature, moisture, fertilization, and management. They observed that white clover and red clover were seldom found in dense, closely grazed quack grass sod (Agropyron repens) whereas alsike clover appeared in comparative abundance. They concluded that there is a possibility that harmful root interactions occur between various species of pasture grasses and legumes, and these interactions are no doubt profoundly influenced by environmental conditions. There is nothing in their work to indicate that harmful root interactions are present between white clover and any of the grasses used for high quality fine turf.

Cooper, Wilson and Barron (14) envisaged a more or less definite succession of plant associations on pasture soils in cool moist regions reflecting different fertility levels. The first association is apt to be bluegrasses and white clover when the fertility level is high. As the fertility level drops, the association becomes one of blue grasses, bent grass, red top, and white clover. As soil fertility is further depleted, the association passes through the bent grass, sweet vernal, and poverty grass stage to a final weed and tree association.

White Clover Years

Beaumont (5) observed that in so-called clover years, white clover appears abundantly in soils supplied with adequate plant nutrients and moisture, and in off years, it disappears from those same areas due to causes which are not understood.

Hollowell (21) stated that white clover is not regular in its persistency of growth, occurring abundantly in some years, but diminishing in others to such an extent that it almost disappears.

Dodd (15) remarked that prevalence and absence of white clover from time to time suggested the idea to some of a more or less regular white clover cycle. As a result of experimental work in Ohio, he supported the theory that weather conditions rather than any natural cycle constitute the main cause for these fluctuations, and these weather variations have no apparent regularity. According to Dodd, if fertilizer treatment, management, and water supply could be kept favorable, a fairly constant white clover content would be maintained regardless of the weather.

Climate and Weather Conditions

Brown (12) stated that climatic conditions have been of less importance than fertilization or species of grass in the maintenance of stands of white clover in an experiment carried on over a three-year period.

Dodd (15) contended that weather conditions are a major factor in the fluctuations of the white clover content of permanent grass areas. He found that an abnormally dry spring, summer, or fall, results in a rapid decline of white clover. During excessively dry seasons, the white clover disappears completely from many lawns and pasture fields. A study of precipitation, temperature, and white clover content points to precipitation as a major factor in white clover fluctuation. If for a total period of six weeks during late spring, summer or fall, the precipitation in each two-week period is less than one inch, clover is diminished. If precipitation is less than one-half inch in each two-week period, clover may die out entirely. Temperature and rate of evaporation are factors also since white clover disappeared with greater precipitation at one center in the state than another. At the center where the clover disappeared, the temperature for July and August was about 4° higher.

Winter Injury

Dodd (15) found that winter injury of clover was not a major depressing factor in any case studied in Ohio, where clover and grass were grown in association. Dry summers and falls, rather than winter weather, appear to have been the more serious depressing factor. When winter injury has occurred, it has been more evident if the pasture was closely grazed or clipped in the fall or when the clover has been growing alone rather than in association with grass.

Disease and Insect Pests

Dodd (15) observed diseases on white clover in Ohio and considered them worthy of further consideration in regard to white clover fluctuations. Dodd also noted that white grubs did serious damage to white clover in some years in Ohio. The grub damage was particularly serious in the case of new seedlings of white clover which were just establishing themselves in the old sod.

EFFECT OF MANAGEMENT AND FERTILIZER PRACTICES

Sprague and Evaul (35) found that clover was controlled by applications of soluble nitrogenous fertilizers in quantities sufficient for vigorous growth of grass when combined with regular close mowing. When the nitrogen was added solely in the form of slowly available organic material, such as bonemeal and alfalfa meal, clover was more plentiful than when adequate nitrogen was available. The applications of lime to acid soils without the addition of nitrogenous fertilizers stimulated clover but when nitrogen fertilizers were also applied, clover was not increased. They concluded that clover is favored by the use of fertilizers containing phosphates and potash and that liming is beneficial to the clover on acid soils. However, when readily available nitrogenous fertilizers are supplied in abundance with such treatment, the grasses present flourish and the abundance of white clover diminishes.

Beaumont (5) working with pastures in Massachusetts from the viewpoint of encouraging clover found that on an alluvial soil,applications of basic slag and low grade sulphate of potash changed a pasture flora largely of bluets (Houstonia catrulea L) and poor grasses to one composed largely of white clover and good grasses.

Beaumont found in other experiments on an upland glacial till that it was possible to transform pasture flora consisting mainly of running cinquefoil (Potentilla canadensis L), haircap moss (Polytrichum communis L), and some grasses and clover to flora consisting mainly of white clover, bent grasses, and Kentucky bluegrass. Beaumont stated that lime was the most effective single material in producing desirable changes in vegetation. Beaumont characterized desirable changes as the transition from weeds and weedy grasses to a flora containing a large percentage of white clover. Beaumont further stated that lime and potash were the most effective combination of two materials; but a combination of lime, potash, and phosphate produced the greatest change in vegetation.

Beaumont noted that addition of nitrogen to the mineral treatments did not reduce the percentage of white clover in one experiment but there was some indication of a trend in that direction in another. He observed that with an abundant supply of the mineral elements calcium, phosphorus, and potash, nitrogen did not depress clover as much as if there was a limited supply of these elements. Potash generally encouraged the presence of white clover.

Rich and Odland (29) reported on an experiment in which varying amounts of nitrogen, phosphoric acid, and potash were applied to study their effect on the species composition and yield of hay crops. Their standard applications were twenty pounds of nitrogen, eighty pounds of phosphoric acid, and one hundred pounds of potash per acre as a top-dressing. They found that reducing the nitrogen had no significant effect on either yield or percentage of legumes in hay, but reducing potash from one hundred to fifty pounds per acre lowered the proportion of legumes from fifty per cent to three per cent and further reduction in potash to twenty-five pounds resulted in less than two per cent legumes.

Blaser and Brady[1] conducted experiments designed to evaluate the effects of nitrogen and potassium fertilization on the productivity and botanical and chemical composition of ladino clover and non-legumes when grown in a mixture. Potassium fertilization stimulated growth of ladino clover but did not directly affect growth of non-legumes. Nitrogen fertilizer increased growth of grasses and decreased growth of leguminous plants in a mixed association. Blaser and Brady attributed the effect of nitrogen on reducing the leguminous associate to competition for potassium. They attributed the cycle of good and poor clover years in part to competition for this element. Soil nitrogen is increased during good clover years and hence grasses which start growth earlier in the following spring than clover are stimulated by an abundance of nitrogen. The leguminous associate with its later start is limited in its growth by the absence of potassium which has been utilized by the rapidly growing grasses.

Brown (12) noted retarding effects of nitrogenous fertilizers on white clover in grassland. He attributed these effects chiefly to increased grass competition caused by the nitrogen.

Brown stated that in grazed permanent pastures, very little clover was present without adding phosphorus. Pastures with complete mineral phosphorus, lime, and potash had the most clover. Omission of potassium had little effect on clover. In the case of a permanent meadow mowed in June for hay and grazed in late summer and fall, the addition of either potash or manure with superphosphate and limestone was very influential in promoting larger amounts of clover.

[1] Blaser, R. E. and Brady, N. C. Nutrient Competition in Plant Association. Cornell University. 1949 Unpublished data.

Brown experimented with effects of minor elements on clover growing on a Charlton fine sandy loam. He noted no appreciable effects on white clover from the use of these elements.

Using one inch height of cut as the standard of comparison, Brown found that lawn mowing to one-half inch for one season greatly decreased both Ladino and Kent clover in Kentucky bluegrass-clover seedings, but Kent clover increased slightly under this management in a mixture with less bluegrass.

Brown found that the amounts of volunteer white clover increased with height of cut when vegetation was mowed during four years under four different methods of fertilizing Kentucky bluegrass and Rhode Island bent turf. The heights of cut were two, three, four, and five inches.

Robinson and Sprague (30), in a comprehensive experiment on clover populations in a Kentucky bluegrass sod, used the following treatments:

1) two levels of soil moisture (natural rainfall with and without irrigation;

2) two levels of nitrogen fertilization (no nitrogen and a very high level of forty pounds of nitrogen per acre from ammonium nitrate in early spring and after each clipping);

3) four clipping treatments (clipping to one-half inch when four inches high; clipping to one inch when four to five inches high; clipping to two inches when five inches high; clipping to one-half inch when three inches high in the early spring and thereafter clipping to one inch when four to five inches high).

Each plot was limed and fertilized with phosphate and potash.

Robinson and Sprague reported that on plots without nitrogen fertilization or irrigation, the clover clipping treatments (one-half inch to one inch) resulted in excellent stands of clover, but clipping to a height of two inches produced a more dense sod of grass with considerably less clover.

They found high rates of nitrogen fertilization without irrigation greatly decreased the stand of clover and clover was practically eliminated on plots clipped to two inches. With the more severe clipping treatments, considerable amounts of clover were maintained even with heavy nitrogen fertilization.

On the irrigated plots, however, Robinson and Sprague found that clipping to one-half inch or one inch resulted in excellent stands of clover even on plots that received as much as 360 pounds of nitrogen per acre per year and fairly good stands of clover were maintained in the two-inch height of clipping.

Robinson and Sprague concluded that clover populations are determined by ability of clover to compete with grass for space, light, moisture, and nutrients. Changes in these factors or of such factors as management practices, winter injury, severe drought, or disease epidemics may greatly change the botanical composition of a pasture. Management practices particularly as they affect the carbohydrate reserve of the grass are especially important. These workers observed that close clipping with ample time for recovery between clipping dates was very effective in maintaining clover.

Dorsey (16) stated that applications of both nitrate of soda and ammonium sulfate on a sward of grass increased yield of hay, but growth was not satisfactory since clover and other legumes were depressed and often eliminated, particularly by ammonium sulfate.

Barnes (4) reported that the immediate effect of treatments of limestone and acid phosphate on worn out pasture in southeast Ohio was a marked increase in percentage of legumes.

Dodd (15) noted in Ohio that if lime is not abundant in the surface soil, its application is necessary for a healthy development of white clover. He considers the need for phosphate a close second to lime and noted some response to potassium on Ohio soils. He noted the usual effect of nitrogen fertilizer to be a reduction in white clover content of a sward.

In his experimental work in Ohio, Dodd observed that clipping to two inches every two weeks from April 17 to October 30 gave the greatest white clover content. He designated the content as 100. Then by delaying the first clipping from April 17 to May 1, he found white clover reduced to 92 per cent of this figure. Delaying the first clipping until May 15 reduced the white clover area to 75 per cent. Clipping it at intervals of four weeks instead of two weeks reduced it to 24 per cent. Cutting at a height of one inch produced on the average only 83 per cent as much white clover as cutting at two inches and cutting at three inches produced 81 per cent as much as when cut at two inches. Clipping at one inch gave a very wide fluctuation. With very favorable white clover weather, wet and not too hot, close clipping had a tendency to increase white clover and reduce grass. With unfavorable weather, hot and dry, close clipping left clover more susceptible to injury. It was apparent that clipping at one-inch intervals was detrimental, except under very favorable conditions. On the other hand, permitting excessive full growth reduced the clover content.

Physiological Considerations of Effect of Applied Nitrogen on the White Clover Content of a Mixed Clover Grass Stand.

Effect on Symbiotic Fixation

The earliest theory made to account for the depressing effect of nitrogenous fertilizers on clover attributed the cause to the inhibiting effect of these materials on root nodule bacteria.

Laurent (24) obtained experimental evidence indicating that nitrates and some constituents of plant sap form a combination which is toxic to the nodule organism.

Mazé (26) put forward a theory relating root invasion to the carbohydrates present in the plant sap. He considered that when the plant is receiving nitrates, carbohydrates may be assimilated at once, so that plant saps with adequate nitrate supply would be low in carbohydrates. On the other hand, plants deficient in nitrogen would contain an excess of carbohydrates circulating in the sap. In the latter case, organic matter, especially carbohydrates secreted by plant roots, would be higher and therefore attract more nodule bacteria.

Strowd (36) also suggests that a sufficiently high concentration of nitrate could be attained in plant sap to injure invading nodule bacteria.

Glöbel (19) has offered the ingenious theory that since nitrogen is fixed in nodules as an organic compound it would experience greater difficulty in diffusing through cell walls than would a rapidly transferable ion like NO_3. This condition would result in an accumulation in nodules of products of fixation with the result that fixation of nitrogen would be impaired and development of nodules stopped.

Hopkins, Wilson and Peterson (23) working with potassium nitrate on red clover plants in agar solution noted that the addition of nitrate nitrogen generally resulted in a decrease in number of nodules formed when concentrations exceeded 20 to 30 parts per million. Complete prevention of nodule formation was not affected by even the highest concentration of nitrate nitrogen used, viz., 160 parts per million. Distribution and size of the nodule, however, were markedly affected by all the concentrations used. Additions of even small quantities of nitrate brought about formation of scattered nodules, largely of the round type on secondary roots whereas normally the nodules are mostly of the long type and are found on the tap root near the crown. The size of the nodules was decreased as the quantity of nitrogen was increased. All concentrations of nitrate nitrogen markedly decreased the fixation of free nitrogen. They noted that if the quantities of nitrate nitrogen added were insufficient for the needs of the plant, the deficit was made up by fixation of atmospheric nitrogen. However, as soon as an excess of nitrogen was provided, the fixation process appeared to be completely suppressed, even though nodules were present.

Hopkins and Fred (22) in experimental work with red clover on agar used potassium nitrate, ammonium sulfate, urea, asparagin, clover seed extract, and yeast extract as nitrogen sources. In a second part of this work, the same nitrogen compounds were used, but 0.5 per cent mannitol was also added. It was found that all nitrogen sources used decreased the size of the nodule formed and this effect became more in evidence as the concentration of the nitrogen compound was increased. The nitrogen compounds were also found to affect the distribution of nodules on the roots. In the untreated control, the nodules were situated for the most part in or near the tap roots. The greater number of these nodules were of a fair size and round in shape. A few were larger and longer. As compared with this condition in the presence of the nitrogen compounds, the nodules were principally on secondary roots and were almost exclusively round and small. The latter condition was attributed to later invasion of the roots by the organism owing to the presence of nitrogen compounds. In the series containing both nitrogen source and mannitol, it was found the nitrogen source no longer affected the distribution of nodules. In these series the nodules were principally in the tap roots. Increasing concentration of the nitrogen compounds did, however, decrease the size of nodules formed.

Hopkins and Fred put forward an hypothesis to support their findings. They stated that nitrogen compounds concerning the six used, are taken up by the plant, thus allowing the carbohydrates synthesized to be assimilated at once. If at any time nodule bacteria penetrate the root hair, they are unable to produce nodules because of the low concentration of sugar in the plant sap. Thus nodules are not formed by the early invaders. As a plant continues to grow it uses up some of the nitrogen source and no longer has a supply of nitrogen adequate to support its growth at the incipient rate. Carbohydrates increase in the plant sap, and as this continues, a concentration is reached which enables the nodule bacteria penetrating the root hair at that time to proliferate and incite nodule formation.

Allison (2) considered carbohydrate supply to be a primary factor in legume symbiosis. He stated that nodule bacteria enter roots at practically any carbohydrate concentration but good nodule development is dependent upon a rather abundant carbohydrate supply in the roots. At a carbohydrate level sufficiently high to permit normal root growth, good nodule development takes place. If carbohydrates are supplied to roots an abnormally large development of roots and nodules with respect to tops may occur. He further stated that failure of nodules to develop abundantly in the presence of excess available nitrogen is due primarily to decreased carbohydrate supply in the roots. Under these conditions, the carbohydrate-nitrogen ratio is narrow and an unusually large percentage of the carbohydrate synthesized is used for top growth leaving less for growth of roots and nodules. Good nodule development takes place only provided there is an adequate supply of carbohydrates for good root growth.

Wilson (44,45) considered that the question as to whether or not free nitrogen can be assimilated in the presence of combined nitrogen could be answered by the effect of the combined nitrogen on the carbon-nitrogen balance in the host. It is probable that free nitrogen will be fixed even in presence of excess combined nitrogen, provided other conditions such as light and carbon dioxide supply are favorable for the maintenance of a carbon-nitrogen ratio sufficiently wide to permit fixation. Wilson's work emphasized the fact that a given environmental factor has a varying effect upon the individual phenomena of root invasion, nodule formation, nitrogen fixation, and host development. Wilson stated that normal symbiosis occurs only when all these processes are coordinated.

Thornton (37,38) observed that as the carbon-nitrogen ratio narrows under a restricted carbohydrate supply, the host tissues are actually parasatized. He considers that true symbiosis exists only under conditions permitting readily available carbohydrates. The addition of carbonaceous compounds to the soil such as sugar, alkaloids, and glucosides, stimulates nodulation and fixation just as increased carbon dioxide pressure does in low carbohydrate plants abundantly supplied with nitrogen. Thornton considers it justifiable to assume that the effect in both cases is achieved through a widening of the carbon-nitrogen ratio.

Loehwing (25) stated that the carbon-nitrogen ratio concept does not explain all problems of nitrogen fixation, but it has been of prime importance in reconciling many apparently contradictory responses, especially in regard to carbonaceous and nitrogenous additions.

The evidence put forward concerning the effect of applied nitrogen on symbiotic nitrogen fixation proves that applied nitrogen inhibits fixation.

The failure of a legume to produce nodule nitrogen in high nitrogen soils affords the legume difficulty in maintaining itself in competition with grasses that have a greater ability to absorb soil nitrogen. Thornton and Nichol (39) state:

> "While non-nodulated legumes can absorb nitrogen directly they do not perform the process as efficiently as grasses and hence legumes are displaced when in competition on highly nitrogen fertilized soils. The effect of high nitrogen adjuncts in suppressing legumes inter-cropped with grass is a forcible illustration of the ease with which the definitely symbiotic inter-relation of grass and legumes can be upset and converted into serious competition."

Effect on Light Relations

Stimulation of the grass by nitrogenous fertilizing results in increased shading of the white clover.

Legumes are known to require relatively large amounts of manufactured food. Virtanen is of the opinion that fixation entails a severe carbohydrate drain upon the legumes, an effect that correlates well with the known high photosynthetic efficiency of legumes over non-legume foliage (40,41,42).

Increased shading of white clover exerts important physiological effects upon it. The lower photosynthetic rates and consequent decrease in manufactured foods brought about by lower light intensities and a change in its quality tend to weaken the clover plant to a point where it may no longer compete with the grass.

Increased shading according to Shirley (32,33,34) influences the nitrogen metabolism of a plant. He stated that unless plants receive enough light for rapid photosynthesis they accumulate but cannot use nitrogen effectively, and, conversely, if they do not receive sufficient nitrogen, they accumulate but cannot utilize carbohydrates effectively. Apparently light intensity affects nitrogen metabolism only indirectly through its influence on carbohydrates.

Fred, Wilson and Wyss (17) reported that soybeans growing in soil poor in nitrogen but inoculated with root nodule bacteria appeared to suffer from nitrogen hunger if the light intensity is high. This condition could be relieved by lowering light intensity or applying nitrogen to the soil. These authors concluded that if plants are starved for nitrogen they are unable to make use of high light intensity and, on the other hand, if they are cultivated in low light intensity they are unable to respond by increased growth to a more generous nitrogen supply.

Blackman and Templeman (11) found that generous applications of sulfate of ammonia and calcium nitrate depressed leaf production of frequently defoliated grass in 37 per cent and 63 per cent daylight. According to these authors, the lower light intensity interfered with elaboration of protein and nitrates tended to accumulate in the plant tissue. The gain in protein as a result of fertilizing under full daylight intensities results in a decrease in percentage of carbohydrates but at the lowest light intensities little effect on the carbohydrate level was brought about by the fertilizing. These writers ascribe the effects of light intensity and nitrogen supply on leaf metabolism and leaf production in part to their indirect effects on metabolism. They stated that a shaded plant tends to use more of its organic food substance to produce leaf and stem tissue than root tissue.

In a later work, Blackman (10) corroborated this hypothesis further. He reported that leaf production by Agrostis tenuis and Festuca rubra subject to frequent defoliation was markedly increased by application of sulfate of ammonia or calcium nitrate provided the plants were exposed to full daylight, but if they were shaded, the same treatment depressed leaf production.

Harrison (20) found that frequent defoliation of bluegrass (Poa pratensis) under comparatively low light conditions leads to exhaustion of carbohydrate reserves of rhizomes and root systems. However, with depletion of carbohydrates there was finally decreased production of blades and subsequently death of the plant. The sequence of events was greatly accelerated by a high nitrogen supply, its absorption and elaboration being at the expense of stored carbohydrates in the underground organs.

While the foregoing experimental evidence is not directly related to white clover, the information can be applied in part to that species. A study of these experiments shows that under low light intensities, leaf production is depressed particularly in the presence of large amounts of soil nitrogen. It is the clover that is subjected to the shading in a stimulated turf. Therefore, the effect of shading on nitrogen metabolism of the clover plant is another factor to consider in studying the effect of nitrogen on the clover-grass ratio of a turf.

Increase in Carbon Dioxide Contents

According to Meyer and Anderson (27) the carbon dioxide content of the stratum of atmosphere immediately above the soil and in the soil atmosphere is greatly increased by application of nitrogenous fertilizer. Increase in content of carbon dioxide is brought about both by stimulation of soil bacteria and secondly by increased respiration of stimulated roots.

If carbon dioxide is the limiting factor in photosynthesis in the clover plant, the increase in this gas should encourage this process.

However, it is probable that the shading of clover by grass tends to make light the limiting factor in the case of the clover. On the other hand, the grass leaves are not subjected to similar shading and it is probable that their photosynthetic rate is increased as a result of the increased carbon dioxide content. No experimental data are available on this particular subject but the writer believes that this factor may have some significance in the competition between grass and clover.

Increase in carbon dioxide content in the soil atmosphere results in a competition for soil oxygen according to Blackman (9). Cannon (13) stated that grass is better suited for this competition than is clover since legumes appear to have both a high oxygen requirement and a lower carbon dioxide tolerance.

Nitrogen Absorption and Cation-Anion Relationships

Definite relationships exist between nitrogen absorption and cation and anion absorption within plants. This factor is of no small significance in the effect of nitrogen on the clover grass ratio.

Parker and Truog (28) demonstrated that a relationship exists between calcium and nitrogen content of plants. Therefore heavy applications of nitrogen may reduce the intake of calcium.

Arnon (3) found that the composition of barley plants is materially influenced by the nitrogen source in the substrata. Plants receiving cationic nitrogen (ammonia nitrogen) had higher phosphorus but lower potassium, calcium, and magnesium content than those receiving anionic nitrogen (nitrate nitrogen). If little nitrate nitrogen was present, absorption of phosphorus, sulfur and chlorine were increased.

Wallace, Toth and Bear (43) put forward the idea that induced cation and anion deficiencies are possible from the theory of cation and anion competition. For example, magnesium deficiency can be induced from the application of large amounts of potassium and, likewise, phosphorus deficiency should be possible from an excess of nitrate nitrogen on other soluble anions.

Shear, Crane and Myers (31) have given a general statement concerning cation and anion relationships in plants as follows:

> "Because of the fact that the cation-anion ratio within the leaf is a constant, it is evident that at any given concentration of anions, any increased accumulation of one or more of the cations must be accompanied by an equivalent decrease in one or more of the other cations. Conversely, at a given concentration of cations any increased accumulation of one or more anions must be accompanied by an equivalent decrease in one or more of the other anions."

From the foregoing a summation absorption value of cations and anions could be written roughly as follows:

$$\frac{Ca^{++} + Mg^{++} + Na^{+} + K^{+} + NH_4^{+}}{Cl^{-} + H_2PO_4^{-} + SO_4^{--} + NO_3^{-}} = \text{Constant}$$

From this approximate summation value it can be seen that additions of ammonium ion to a soil might depress the absorption of calcium, magnesium, and potassium. It is known that clover has a high requirement of these three elements, particularly potassium and it can therefore be seen that applications of a fertilizer containing the ammonium might adversely affect clover in turf.

Similarly applications of nitrate nitrogen would affect the uptake of phosphorus. Clover also has a high requirement for this element.

Application of the summation value is significant in determining the grass-clover ratio of a turf. This theory correlates well with known experimental evidence that many grasses thrive on soils lower in calcium, potassium, and phosphorus than is required by legumes. Moreover, NH_4^{+}

replaces K^+ from the soil complexes. An application of an ammonium salt therefore results in leaching of potassium from the root zone.

Blackman's Experiments and Hypotheses

G. E. Blackman, working in Great Britain, carried out a number of experiments related to the effect of applied nitrogen on the clover-grass ratio of a turf.

Blackman (6,7) first advanced the hypothesis that reduction of some species including white clover by treatment with ammonium salts was due to a toxic action of the absorbed ammonium ions. He considered Trifolium repens in particular. The ammonium compounds by combining with the carbohydrates to form amide compounds would lead, if the uptake of such ions was rapid, to a condition where the depleted reserves would be insufficient for both replacement of leaf tissue removed by constant defoliation and for maintaining the concentration of ammonium ions below an injurious level. Blackman believed that if the total available carbohydrate supply could by some means be increased then the reduction of clover should to some extent be lessened; alternatively the same effect would be produced by lowering the rate of absorption of ammonium salts.

Blackman agreed that the addition of sucrose to sulfate of ammonia should lead to a slower rate of reduction of clover since absorption of sucrose with ammonium ions should reduce the drain on the carbohydrate reserve. Blackman bore in mind that the uptake of nitrogen might be greatly reduced in the presence of sucrose, for such a source of carbon might lead to a large increase in soil microflora, and in consequence to a considerable secondary utilization of the added nitrogen.

Having put forward this hypothesis, Blackman published results of a series of experiments in a later paper (8). He found that using sucrose alone gave no appreciable effect. From this he concluded that the uptake of nitrogen by plants was not greatly reduced by addition of sucrose.

He found that an application of sulfate of ammonia led to greater reduction in the population of Trifolium repens than did an application of nitrate of soda, calcium nitrate, and urea given at equivalent nitrogen rates. But adding sucrose at ten pounds per thousand square feet with each application of sulfate of ammonia reduced the clover content at a slower rate than did sulfate of ammonia alone. Sucrose added to either calcium nitrate or nitrate of soda had little effect on their action.

With these results Blackman concluded that his hypothesis explained the mechanism whereby clover was reduced and grass stimulated by ammonium salts.

However, some years later, Blackman (9) took cognizance of the fact that the reduction might be a question of the competition for light, the taller growing grasses shading the clover. It seemed likely to Blackman that at low light intensities, at a low rate of photosynthesis, the effect of applications of ammonium compounds would be much more pronounced. Accordingly, he carried out a series of experiments on decreasing light intensities alone and on decreasing light intensities with ammonium sulfate.

He found that decreasing light intensities without addition of fertilizers reduced the amount of clover markedly, whereas the effect of additional nitrogen was less pronounced with decreasing light intensities.

On the basis of these experiments Blackman concluded that the decrease in clover content brought about by shading is a direct effect on clover. On the other hand, reduction in clover associated with additional nitrogen is primarily due to competition. The intensity of this competitinn is linked with the active growth of grasses, and is therefore greatest under conditions where light intensity is not limiting their growth. Competition for nitrogen plays a part since with a high external concentration of inorganic nitrogen, nitrogen fixation will be at a minimum.

In this same paper Blackman concludes that the greater reduction in clover brought about by ammonium nitrogen as against nitrate nitrogen can in no way be associated with a direct toxic effect of absorbed ammonium ions. Rather the depression of white clover by any nitrogenous manuring is necessarily related to the presence of grasses since clover does not absorb nitrogen as readily as do some grasses.

EXPERIMENTAL

The review of literature shows that adjustments of cultural management practices, including watering, height of cut, and fertilizer treatment, can be effected in such a way that in a mixed turf, grasses are favored and white clover is depressed.

Since height of cut and supplementary irrigation on a sward of turf are more or less predetermined, it is suggested that the most practical means of depressing white clover is by fertilizer treatments. Experimental evidence has shown that periodic applications of nitrogenous fertilizers to closely cut or grazed turf reduce white clover. Therefore, three experiments were conducted to determine the types and rates of nitrogenous fertilizer most effective in eradicating clover from a turf.

Materials used were sulfate of ammonia (20.5% nitrogen), nitrate of soda (16% nitrogen), castor pomace (6% nitrogen, 1.5% phosphoric acid and 1.5% potash), and urea in the form of "uramon" (42% nitrogen).

A complete 5-8-7 fertilizer was also used in one of these experiments. This same fertilizer was used for the general application. Its nitrogen source was ammoniacal, its phosphoric acid being derived from superphosphate, and its potassium oxide from potassium sulfate, 1 per cent, and muriate of potash, 6 per cent. The fertilizer contained 2 per cent magnesium oxide.

Effect of Nitrogenous Materials on the White Clover Content of a Lawn Area

In 1948, an area of campus lawn with a heavy white clover content was selected and divided into plots each two feet by two feet, as shown in Figure 1.

The soil type was a sandy loam with a pH of 6.0, medium high nitrogen and magnesium, medium phosphoric acid, low calcium, and low potash content.

The lawn was mowed once a week at a height of cut varying from one to one-half inch. It received no irrigation beyond normal rainfall and no fertilizer treatments other than those applied in the experiment.

Rate of nitrogenous materials used in pounds of nitrogen per thousand square feet were:

Sulfate of ammonia	2, 1 and 0.2
Nitrate of soda	1.6, 0.8 and 0.16
Castor pomace	1.8, 0.96 and 0.24
Uramon	2.10, 1.05 and 0.21

Check plots were retained. The experiment was conducted in quadruplicate.

Applications of the materials were made on July 1, and repeated on July 20. Estimates of the amounts of clover present were made on July 1, July 17, and August 16, by comparing each plot to a standard check plot. Numerical counts were not made because the object of the experiment was merely to determine whether it was feasible to reduce clover in a turf by application of nitrogen. This was in the nature of a preliminary experiment.

Results

Complete data are shown in Table I.

FIGURE I

DIAGRAM SHOWING TREATMENTS OF LAWN PLOTS

EACH PLOT = 2 FEET x 2 FEET

RATE = POUNDS OF NITROGEN PER 1000 SQUARE FEET IN EACH APPLICATION

1 CASTOR POMACE 1.8 LBS	2 URAMON 2.1 LBS	3 NITRATE OF SODA 1.6 LBS	4 SULPHATE OF AMMONIA 2.0 LBS
5 CASTOR POMACE 0.24 LBS	6 URAMON 0.21 LBS	7 NITRATE OF SODA 0.16 LBS	8 CHECK 0 LBS
9 CASTOR POMACE 0.96 LBS	10 URAMON 1.05 LBS	11 NITRATE OF SODA 0.80 LBS	12 SULPHATE OF AMMONIA 0.20 LBS
13 SULPHATE OF AMMONIA 0.20 LBS	14 CASTOR POMACE 1.8 LBS	15 URAMON 2.10 LBS	16 SULPHATE OF AMMONIA 1.0 LBS

17 SULPHATE OF AMMONIA 0.20 LBS	18 CASTOR POMACE 0.24 LBS	19 CHECK 0 LBS	20 NITRATE OF SODA 1.6 LBS
21 SULPHATE OF AMMINIA 1.0 LBS	22 CASTOR POMACE 0.96 LBS	23 URAMON 0.21 LBS	24 NITRATE OF SODA 0.16 LBS
25 NITRATE OF SODA 1.62 LBS	26 SULPHATE OF AMMINA 2.0 LBS	27 URAMON 1.05 LBS	28 NITRATE OF SODA 0.80 LBS
29 NITRATE OF SODA 0.16 LBS	30 CHECK 0 LBS	31 CASTOR POMACE 0.24 LBS	32 URAMON 2.1 LBS
33 NITRATE OF SODA 0.80 LBS	34 SULPHATE OF AMMONIA 0.20 LBS	35 CASTOR POMACE 0.24 LBS	36 URAMON 0.21 LBS
37 URAMON 2.10 LBS	38 SULPHATE OF AMMONIA 1.0 LBS	39 CASTOR POMACE 0.96 LBS	40 URAMON 1.05 LBS

41 CHECK 0 LBS	42 NITRATE OF SODA 1.6 LBS	43 SULPHATE OF AMMONIA 2.0 LBS	44 CASTOR POMACE 1.8 LBS
45 URAMON 0.21 LBS	46 NITRATE OF SODA 0.16 LBS	47 SULPHATE OF AMMONIA 0.20 LBS	48 CASTOR POMACE 0.24 LBS
49 URAMON 1.05 LBS	50 NITRATE OF SODA 0.80 LBS	51 SULPHATE OF AMMONIA 1.0 LBS	52 CASTOR POMACE 0.96 LBS

Control Plots: With the exception of one plot which showed a slight decrease in white clover, these plots showed no change over the period of the experiment.

Sulfate of Ammonia: Two of the plots receiving this material at the rate of two pounds of nitrogen per one thousand square feet per application showed an appreciable decrease and two, a slight decrease in white clover content after the two applications.

One of the plots receiving sulfate of ammonia at the rate of one pound per thousand square feet per application showed an appreciable decrease and three, a slight decrease in white clover content after two applications.

Nitrate of Soda: Three of the plots at the rate of 1.6 pounds of nitrogen per one thousand square feet per application showed no change after two applications, while the fourth showed a slight decrease.

The four plots receiving nitrate of soda at the rate of 0.8 pounds of nitrogen per thousand square feet per application showed an increase in the amount of clover present; two, a slight decrease; and one, no change.

Three of the plots receiving castor pomace at the rate of 0.96 pounds of nitrogen per application showed no change after two applications and one a slight decrease in clover content.

Two of the plots at the rate of 0.24 pounds of nitrogen per one thousand square feet per application showed no change in the clover content, while one showed a slight increase and one a slight decrease.

Uramon: One of the plots receiving uramon at the rate of 2.10 pounds per one thousand square feet per application showed an appreciable decrease after two applications, while the other three at this rate showed no change.

Two of the plots receiving this fertilizer at 1.05 pounds per thousand square feet showed an appreciable decrease and two showed no change in the white clover content.

The four plots receiving 0.24 pounds of nitrogen in this form after two applications showed no change.

DISCUSSION

While no absolute conclusions are drawn from this experiment, the results do indicate that it is feasible to reduce clover in a turf by the use of two applications of sulfate of ammonia at the rate of two pounds of nitrogen per thousand square feet. Although clover was reduced it was not eradicated completely by these applications. There is some indication that other inorganic fertilizers, if applied at heavier rates, tend to depress clover.

Effect of a Single Application of a Nitrogenous Material

In June 1948, wooden flats were planted with a mixture of Astoria Colonial Bent (Agrostis tenuis) and white clover at the rate of four pounds and 0.5 pounds per thousand square feet respectively.

A sandy loam soil was used with a pH of 5.3. One-half the flats were limed at the rate of one hundred pounds of ground dolomitic limestone (20% MgO, 30% CaO) per thousand square feet.

A 5-8-7 complete fertilizer was used as a pre-seeding fertilizer on all flats at the rate of ten pounds per thousand square feet.

After germination of seed, each flat was maintained at one-half inch height of cut and the moisture content was retained at approximately field capacity.

The same nitrogenous fertilizer at the same rate as the first experiment was used. The experiment was conducted in duplicate with six control flats.

A count was made of the clover leaves in an equal area of each flat prior to applying the fertilizer materials. Twenty-one days after application of the fertilizer material these sections were recounted. No further application of materials was made, but twenty-eight days after this, or forty-nine days from the date the fertilizers were first applied, the sections were again counted to see if clover was reappearing.

Results

Complete data are shown in Table II.

Sulfate of Ammonia:

Twenty-one days after a single application at the rate of two pounds of nitrogen per thousand square feet, the content of clover was reduced markedly on both the limed and unlimed plots to an average content of 45 per cent of the original. But forty-nine days after the application, the clover had returned close to its original level in two of the limed flats and two of the unlimed flats. On the third limed and the third unlimed flats some recovery was noted.

Twenty-one days after a single application of this fertilizer at one pound per thousand square feet, two of the limed flats showed reduction in clover leaves to a content less than 45 per cent of the original and the third a reduction to 65 per cent. Forty-nine days after the application, the clover content in the third flat had returned almost to its original level, while on those flats that had shown a significant reduction, recovery almost to the original level was noted in one, while in the other there was little change.

Twenty-one days after the one-pound application to the unlimed flats, two of the flats showed reduction to 51 per cent and 66 per cent of original respectively while in the third, there was little change, the content being 86 per cent of original. After forty-nine days, the clover in one of the flats that had shown a decrease originally had continued to decrease while in the others there was little change. The clover content in the flat that had shown little original reduction had increased above its original level after forty-nine days.

In the limed and unlimed flats that received an application of sulfate of ammonia at the rate of 0.20 pounds of nitrogen per thousand square feet, there was no significant change after twenty-one days. After forty-nine days there was still no marked change except that the clover in one of the unlimed flats had decreased markedly to 51 per cent of original.

Nitrate of soda:

The three limed and three unlimed flats receiving an application at the rate of 1.6 pounds of nitrogen per thousand square feet, showed a reduction in clover content after twenty-one days to a content averaging 63 per cent of the original. After forty-nine days, all of these flats showed recovery except one of the unlimed flats which had a slight further reduction. The clover in one of the limed flats had increased above its original level.

Two of the limed flats receiving an application of this fertilizer at the rate of 0.80 pounds of nitrogen per thousand square feet showed some reduction after twenty-one days to 66 per cent and 70 per cent of original respectively. On all the other flats, limed or unlimed, treated at this rate, there was very little change after twenty-one days. After forty-nine days both flats that showed an original reduction had recovered somewhat to over 75 per cent of the original. In the remaining flats there was little change.

In the limed or unlimed flats that had received an application of nitrate of soda at the rate of 0.16 pounds of nitrogen per thousand square feet, there was no significant change after twenty-one or forty-nine days.

<u>Uramon</u>:

On both limed and unlimed flats, there was a slight reduction in clover to an average of 80 per cent of the original twenty-one days after an application of the material at 2.10 pounds of nitrogen per thousand square feet. After 1.05 pounds of nitrogen per thousand square feet in this form clover was also reduced after 21 days to an average of 80 per cent of the original content in the limed and unlimed flats.

At the lowest rate of application there was no significant change in clover content.

<u>Castor Pomace</u>:

A slight increase in clover to a content averaging 105 per cent of the original was noted on those flats receiving an application of this material at 1.8 pounds of nitrogen per thousand square feet. Medium or light rates showed little effect in either decreasing or diminishing the clover content.

DISCUSSION

These results show that a single application of sulfate of ammonia at the rate of two pounds of nitrogen per thousand square feet or at half that rate tends to depress white clover but the legume recovers rapidly. There was no marked difference in behavior of the clover either in depression or recovery between limed and unlimed flats.

After the heavy application of nitrate of soda some reduction in clover was noted, but recovery was rapid. At medium and lower rates there was very little change brought about in clover content. After heavy and medium applications of uramon there was a decrease but this was too slight to be of practical importance.

Castor pomace at the heaviest rate showed a tendency to encourage clover slightly with medium and light rates showing little effect.

It was concluded that the rates used of all these fertilizers were either too low to reduce the clover sufficiently or that it is necessary to repeat the application to permanently depress the legume.

Effect of Three Applications of Nitrogenous Materials at Two Week Intervals

From the previous experiment it appeared likely that more than one application is necessary to eradicate clover permanently.

Clay bulb pots were seeded in May 1949 with a mixture of Astoria Colonial Bent and White Clover at the rate of two pounds and 0.5 pounds per thousand square feet respectively. Prior to seeding, ground limestone at 50 pounds and a complete 5-8-7 fertilizer at twenty pounds per thousand square feet were applied to each pot.

Rates of nitrogenous materials used in pounds of nitrogen per thousand square feet were:

Sulfate of ammonia	4.0, 2.0 and 1.0
Nitrate of soda	4.0, 2.0 and 1.0
Castor pomace	4.2, 2.1 and 1.05
Uramon	4.2, 2.1 and 1.05
Complete 5-8-7 fertilizer	4.0

Applications of materials at these rates were made on July 1, July 14 and August 1.

On July 23, all pots were limed and on August 4, all pots received an application of muriate of potash. These materials were applied at a rate of 50 pounds and two pounds per thousand square feet respectively. The moisture content of the pots was retained at approximately field capacity and the grass was cut to one-half inch.

Measurements of clover content were made by direct count of the leaves. Counts were made on June 28, July 12, July 25, August 11, and September 8. The purpose of the count made on September 8 was to ascertain the degree of recovery in the clover.

Results:

Complete data are shown in Table III.

Sulfate of ammonia:

Three applications of this material at four pounds of nitrogen per thousand square feet almost completely eradicated the legume and four weeks later there was very little recovery by the clover.

After three applications of the material at a rate equivalent to two pounds of nitrogen per thousand square feet, the clover content decreased in two cases by 70 per cent and 55 per cent respectively of original. In the third instance the clover decreased only 26 per cent. There was little recovery in the clover four weeks later in these three pots.

At a rate equivalent to one pound of nitrogen per thousand square feet, three applications of this material did not markedly decrease the clover content. The decrease averaged 13 per cent. This reduction was no greater than in the controls.

Nitrate of soda:

Three applications of this material at a rate equivalent to four pounds of nitrogen per thousand square feet decreased clover content markedly in all three instances. The average reduction was 92 per cent. There was practically no recovery in these pots.

At the rate of two pounds of nitrogen per thousand square feet there was a marked reduction in clover in one instance by 90 per cent but in the other two pots the reduction was slight, being only 25 per cent and 30 per cent respectively. In the pots where reduction was noted there was no recovery.

At the rate of one pound of nitrogen per thousand square feet the reduction in clover was approximately the same as the controls.

Castor Pomace:

Three applications of this material at a rate equivalent to 4.2 pounds of nitrogen per thousand square feet reduced the clover just over 50 per cent in two cases but in the third pot there was an increase of 12.5 per cent.

The same number of applications at a rate equivalent to 2.1 pounds of nitrogen per thousand square feet reduced the clover in one instance by 58 per cent but in the other two pots the reduction was approximately the same as in the controls. The clover recovered rapidly in all three instances.

At a rate equivalent to 1.05 pounds of nitrogen per thousand square feet, there was a marked increase in clover by 76 per cent in one of the pots and slight increases of 4 per cent and 10 per cent in the other two.

Uramon:

Three applications of this material at a rate equivalent to 4.2 pounds of nitrogen per thousand square feet reduced the clover markedly in all three instances with no recovery apparent by the last counting. The average decrease in these three pots was 83 per cent.

At the rate of 2.1 pounds of nitrogen the legume was reduced markedly in two instances by 90 per cent and 94 per cent respectively and in the third by 39 per cent with no recovery apparent in any of the pots.

At a rate equivalent to 1.05 pounds of nitrogen the clover was reduced by 60 per cent in one case, by 35 per cent in another, and only by 6 per cent in the third.

Complete fertilizer (analysis 5-8-7)

At a rate equivalent to four pounds of nitrogen per thousand square feet, clover was reduced markedly by an average amount of 90 per cent in all three instances with no apparent recovery by the date of the last count.

DISCUSSION

Three applications of sulfate of ammonia, nitrate of soda, and urea at the heavy and medium rates were effective in reducing clover content. Likewise the complete 5-8-7 fertilizer at the rate used was effective. The organic fertilizer, castor pomace, was not nearly so effective.

Recovery after three applications of the inorganic fertilizers was not marked.

The results indicate that at least three applications of inorganic materials at two week intervals are necessary to permanently reduce clover. Rate of application must be two to four times the normal application of one pound of nitrogen per thousand square feet.

CONCLUSIONS AND RECOMMENDATIONS

The experimental evidence from greenhouse data indicates that white clover can be eradicated from a turf in several weeks by periodic applications of nitrogenous fertilizers.

Inorganic fertilizers are far more effective in eradicating or reducing clover than the one organic fertilizer used in these experiments. Of the inorganics used, sulfate of ammonia appears to be the most effective.

It was found by qualitative experiments on near-by golf courses that similar applications could be made under field conditions to putting greens.

It must be noted, however, that there are many dangers in overstimulating a turf by nitrogen and complications that may arise from its use are equally as serious as the presence of clover. The following recommendations are made with this in mind. These recommendations for the most part apply to limited turf areas such as putting greens, the treatment being too expensive for larger areas.

In early spring, the area should receive a normal fertilizing treatment but if the clover content is high or on the increase, no fertilizers other than nitrogenous materials should be applied for the balance of the season.

Around mid-May, the heavily infested areas should be aerated in order to relieve compaction. Three applications of nitrogen should then be applied in the inorganic form at two-week intervals.

The rate of application for most conditions should not exceed three pounds of nitrogen per thousand square feet and should not be less than two pounds. The fertilizer may be applied in dry or spray form but serious damage will result to the turf if the material is not watered in carefully and thoroughly. Throughout the season, the turf grower must be prepared for more than usual fungus attacks on his stimulated turf.

Concurrently with the nitrogen treatments, the general watering program should be checked because over-watering will encourage the legume.

Under most circumstances, the three applications will eradicate the clover. If they do not, a fourth application may be made, but after four applications, the treatments should be discontinued even if not successful.

For at least six weeks after treatment, no further fertilizer application should be made, but thereafter the turf grower may return to a normal fertilizing program. In the event that sulfate of ammonia is used, the treated areas should be limed in late autumn.

SUMMARY

In order to compile the factors which influence the content of white clover in a turf, literature concerning its habits of growth and experimental work conducted in relation to management and fertilizer practices were reviewed.

The species Trifolium repens is persistent under a wide range of environmental conditions.

Generally, clay and loam soils with adequate moisture are better suited to white clover than are light soils. It is not generally present in abundance on shallow upland soil types or on heavy soils that dry out quickly. The species is much more tolerant of an excess of water than of a deficiency.

The optimum pH for its growth is believed to be above 6.0, but this varies with the quantity and quality of mineral elements present in the soil. White clover has been noted to volunteer most freely in soils with a slightly acid reaction.

As a profusely-seeding and creeping perennial, white clover normally

grows in association with grass. It volunteers freely and stands can be obtained in grass without resort to seeding.

A more or less definite succession of plant associations on pasture soils at different fertility levels has been envisaged. White clover is present in an association dependent on high fertility levels.

In so-called clover years, white clover is present in abundance while in other years it is much less abundant.

The maintenance of a high level of water appears to favor clover. This factor may largely offset the depressing effect of nitrogen fertilizers and excessive long and short cutting.

A number of hypotheses are reviewed in regard to the depression of white clover as a result of nitrogenous fertilizing. Although there seems to be no single reason for the depressing effect of nitrogenous fertilizer on clover in a turf, a number of conditions are evaluated as contributing factors. Some probable reasons are listed as follows:

1. Applied nitrogen inhibits nitrogen fixation. In the competition that follows for soil nitrogen, grass is favored.

2. Nitrogen stimulation of a turf results in:

    a. decreased photosynthesis in the white clover due to increased shading by the grasses;

    b. under low light intensities such as the clover is subjected to, leaf production is depressed particularly in the presence of large amounts of soil nitrogen;

    c. increased carbon dioxide of the atmosphere probably increases photosynthesis in the unshaded grass blade but has little effect on shaded clover.

    d. increased carbon dioxide of the soil atmosphere results in competition for soil oxygen, another competition in which the grass is favored.

3. Ammonium nitrogen absorption lowers the intake of potassium, calcium, and magnesium. Nitrate nitrogen absorption lowers phosphorus intake. These elements are all required in relatively large amounts by white clover and therefore it is probable that a deficiency factor has been induced.

4. Competition for potassium between the grass and clover results from stimulation of the grass.

The type and rate of nitrogen fertilizer most effective in eliminating clover was investigated experimentally. It was found that three inorganic fertilizers, sulfate of ammonia, uramon, and nitrate of soda, applied three times at a rate of two to four pounds of nitrogen per thousand square feet per application, were effective in reducing clover under greenhouse conditions. A fourth fertilizer, an organic nitrogen source, castor pomace, was not nearly so effective. A complete 5-8-7 fertilizer applied at the rate of four pounds of nitrogen did eliminate clover.

Qualitative experiments on near-by golf courses showed that similar applications could be made under field conditions to putting greens.

Recommendations based on conclusions reached are made.

TABLE I

Estimated Amounts of White Clover Present in a Lawn Under Different Treatments

Plot No.	Nitrogenous Material	Nitrogen Applied in each application lbs./1000	Estimated Clover Present			Change During Treatment
		Application July 1 and 20	July 1	July 17	August 16	
1	Castor Pomace	1.8	light	medium	medium	increase
2	Uramon	2.1	heavy	heavy	heavy	none
3	Nitrate/soda	1.6	heavy	heavy	heavy	none
4	Sulfate/ammonia	2.0	medium	light	light	appreciable decrease
5	Castor Pomace	0.24	medium	medium	medium	none
6	Uramon	0.21	heavy	heavy	heavy	none
7	Nitrate/soda	0.16	heavy	heavy	heavy	none
8	Check	0.	heavy	heavy	heavy	none
9	Castor Pomace	0.96	medium	medium	medium	none
10	Uramon	1.05	heavy	heavy	heavy	none
11	Nitrate/soda	0.80	heavy	heavy	heavy	none
12	Sulfate/ammonia	0.20	heavy	heavy	heavy	none
13	Sulfate/ammonia	0.20	heavy	medium	medium	slight decrease
14	Castor Pomace	1.8	medium	heavy	medium	nc change
15	Uramon	2.10	heavy	heavy	heavy	no change
16	Sulfate/ammonia	1.0	heavy	medium	medium	slight decrease
17	Sulfate/ammonia	0.20	heavy	heavy	heavy	none
18	Castor Pomace	0.24	heavy	heavy	heavy	none
19	Check	0.	heavy	heavy	heavy	none
20	Nitrate/soda	1.6	heavy	medium	medium	slight decrease

Plot No.	Nitrogenous Material	Nitrogen Applied in each application lbs./1000	Estimated Clover Present			Change during Treatment
		Application July 1 and 20	July 1	July 17	August 16	
21	Sulfate/ammonia	1.0	heavy	medium	medium	slight decrease
22	Castor Pomace	0.96	heavy	heavy	heavy	none
23	Uramon	0.21	medium	medium	medium	none
24	Nitrate/soda	0.16	heavy	medium	medium	slight decrease
25	Nitrate/soda	1.6	medium	light	medium	none
26	Sulfate/ammonia	2.0	heavy	light	light	appreciable decrease
27	Uramon	1.05	heavy	medium	light	appreciable decrease
28	Nitrate/soda	0.80	medium	medium	medium	none
29	Nitrate/soda	0.16	heavy	heavy	heavy	none
30	Check	0.	heavy	medium	medium	slight decrease
31	Castor Pomace	1.8	heavy	medium	medium	slight decrease
32	Uramon	2.1	medium	medium	medium	none
33	Nitrate/soda	0.80	heavy	heavy	heavy	none
34	Sulfate/ammonia	0.20	medium	medium	medium	none
35	Castor Pomace	0.24	heavy	heavy	medium	slight decrease
36	Uramon	0.21	light	light	light	none
37	Uramon	2.10	heavy	light	light	appreciable decrease
38	Sulfate/ammonia	1.0	heavy	medium	light	appreciable decrease
39	Castor Pomace	0.96	heavy	medium	medium	slight decrease
40	Uramon	1.05	heavy	medium	light	appreciable decrease
41	Check	0.0	heavy	heavy	heavy	none
42	Nitrate/soda	1.6	medium	medium	medium	none

Plot No.	Nitrogenous Material	Nitrogen applied in each application lbs./1000	Estimated Clover Present			Change during Treatment
		Application July 1 & 20	July 1	July 17	August 16	
43	Sulfate/ammonia	2.0	heavy	medium	medium	Slight decrease
44	Castor Pomace	1.8	heavy	medium	medium	Slight decrease
45	Uramon	0.21	heavy	heavy	heavy	none
46	Nitrate/soda	0.16	heavy	heavy	heavy	none
47	Sulfate/ammonia	0.20	heavy	heavy	heavy	none
48	Castor Pomace	0.24	light	light	medium	slight increase
49	Uramon	1.05	medium	light	medium	none
50	Nitrate/soda	0.80	heavy	heavy	heavy	none
51	Sulfate/ammonia	1.0	heavy	medium	medium	slight decrease
52	Castor Pomace	0.96	light	light	light	none

TABLE II

Effect of a Single Application of Nitrogenous Material on the White Clover Content of a Mixed Clover-Grass Turf

Plot	Lime Treatment	Nitrogenous Material	Lbs. Nitrogen-1000 sq/ft	Clover leaves before treatment	Clover leaves 21 days after treatment	% of original	Clover leaves 49 days after treatment	% of original
1	lime	sulfate of ammonia	2.0	109	48	44	93	85
2	unlimed	" " "	2.0	127	38	30	121	95
3	limed	" " "	2.0	165	79	48	128	77
4	unlimed	" " "	2.0	170	90	53	154	90
5	limed	" " "	2.0	170	97	57	122	68
6	unlimed	" " "	2.0	183	67	36	96	52
7	limed	" " "	1.0	180	70	38	108	60
8	unlimed	" " "	1.0	105	90	86	133	127
9	limed	" " "	1.0	106	48	44	96	41
10	unlimed	" " "	1.0	191	102	51	105	52
11	limed	" " "	1.0	145	94	65	133	91
12	unlimed	" " "	1.0	103	68	66	41	40
13	limed	" " "	0.2	48	55	115	47	100
14	unlimed	" " "	0.2	74	78	105	78	105
15	limed	" " "	0.2	87	72	83	88	100
16	unlimed	" " "	0.2	125	132	106	128	102
17	limed	" " "	0.2	94	98	104	104	110
18	unlimed	" " "	0.2	136	132	96	70	51
19	limed	nitrate of soda	1.6	53	34	64	40	75
20	unlimed	nitrate of soda	1.6	120	46	38	92	76

TABLE II

Plot	Lime Treatment	Nitrogenous Material	Lbs. Nitrogen/1000 sq. ft.	Clover leaves before treatment	Clover leaves 21 days after treatment	% of original	Clover leaves 49 days after treatment	% of original
21	limed	nitrate of soda	1.6	115	84	73	98	85
22	unlimed	" " "	1.6	161	111	70	169	105
23	limed	" " "	1.6	200	144	72	130	65
24	unlimed	" " "	1.6	185	108	58	122	66
25	limed	" " "	0.8	233	160	70	178	76
26	unlimed	" " "	0.8	295	256	87	230	80
27	limed	" " "	0.8	177	117	66	148	83
28	unlimed	" " "	0.8	148	145	99	132	90
29	limed	" " "	0.8	116	124	101	122	106
30	unlimed	" " "	0.8	158	159	100	124	78
31	limed	" " "	0.16	121	132	109	88	73
32	unlimed	" " "	0.16	106	100	94	41	38
33	limed	" " "	0.16	75	81	108	58	78
34	unlimed	" " "	0.16	70	62	88	64	90
35	limed	" " "	0.16	84	87	103	89	105
36	unlimed	" " "	0.16	77	85	110	93	120
37	limed	uramon	2.10	157	137	87	162	103
38	unlimed	"	2.10	172	135	80	145	85
39	limed	"	2.10	85	29	34	49	57
40	unlimed	"	2.10	160	140	87	177	110
41	limed	"	2.10	109	106	97	123	113
42		"	2.10	86	84	98	73	86

TABLE II

Plot No.	Lime Treatment	Nitrogenous Material	Lbs. Nitrogen/1000 sq. ft.	Clover leaves before treatment	Clover leaves 21 days after treatment	% of original	Clover leaves 49 days after treatment	% of original
43	limed	uramon	1.05	61	57	93	55	91
44	unlimed	"	1.05	51	56	109	48	94
45	limed	"	1.05	99	95	96	111	112
46	unlimed	"	1.05	67	34	50	40	60
47	limed	"	1.05	140	96	68	120	85
48	unlimed	"	1.05	116	78	67	76	65
49	limed	"	0.5	122	120	98	112	92
50	unlimed	"	0.5	122	75	61	83	68
51	limed	"	0.5	131	135	102	149	113
52	unlimed	"	0.5	85	77	90	63	74
53	limed	"	0.5	86	140	163	132	150
54	unlimed	"	0.5	78	84	108	93	120
55	limed	castor pomace	1.8	92	112	121	130	141
56	unlimed	" "	1.8	89	94	105	102	114
57	limed	" "	1.8	48	49	100	63	131
58	unlimed	" "	1.8	92	84	91	108	117
59	limed	" "	1.8	58	54	93	92	160
60	unlimed	" "	1.8	83	103	124	94	113
61	limed	" "	0.96	101	83	82	110	110
62	unlimed	" "	0.96	190	166	87	168	88
63	limed	" "	0.96	106	112	106	102	96
64	unlimed	" "	0.96	40	32	80	64	160

TABLE II

Plot No.	Lime Treatment	Nitrogenous Material	Lbs. Nitrogen/1000 sq. ft.	Clover leaves before treatment	Clover leaves 21 days after treatment	% of original	Clover leaves 49 days after treatment	% of original
65	limed	castor pomace	0.96	120	122	101	165	140
66	unlimed	" "	0.96	146	126	86	142	98
67	limed	" "	0.24	225	210	93	238	106
68	unlimed	" "	0.24	130	136	104	109	84
69	limed	" "	0.24	74	78	103	92	124
70	unlimed	" "	0.24	75	79	105	82	102
71	limed	" "	0.24	70	68	97	43	61
72	unlimed	" "	0.24	35	48	137	42	120
73	limed	check	0.	71	78	109	63	89
74	unlimed	"	0.	89	110	123	132	148
75	limed	"	0.	160	148	92	112	70
76	unlimed	"	0.	156	178	114	184	118
77	limed	"	0.	158	138	87	120	76
78	unlimed	"	0.	187	152	81	148	80

TABLE III

Effect of Three Applications of a Nitrogenous Material

Plot	Nitrogenous Material	N in each application. Lbs. per 1000 sq. ft. July 1, 14. Aug. 1.	Clover leaves June 28	Clover leaves July 12	Clover leaves July 25	Clover leaves Aug. 11	% decrease June 28 to Aug. 11	Clover leaves Sept. 8	Recovery. Increase in clover leaves Aug. 11-Sept. 8
1	Sulfate of Ammonia	4	200	210	15	0	100	0	0
2	" " "	2	180	170	75	55	70	80	10
3	" " "	1	200	140	150	175	125	165	-10
4	" " "	4	170	100	15	15	91	20	5
5	" " "	2	200	165	85	90	55	50	-40
6	" " "	1	170	125	130	135	20	185	50
7	" " "	4	145	135	25	20	86	25	5
8	" " "	2	170	115	120	125	26	115	-10
9	" " "	1	120	100	110	130	8	145	15
10	Nitrate of Soda	4	150	65	15	10	93	10	0
11	" " "	2	145	170	130	100	25	90	-20
12	" " "	1	110	105	95	96	13.5	85	-10
13	" " "	4	140	120	45	10	93	5	-5
14	" " "	2	200	95	35	20	90	5	-15
15	" " "	1	130	110	85	95	27	100	5
16	" " "	4	200	115	40	25	87.5	40	15
17	" " "	2	185	145	150	130	30	175	45
18	" " "	1	145	130	125	115	21	120	5
19	Castor Pomace	4.2	100	95	40	45	55	85	40
20	" "	2.1	190	135	80	80	58	95	15

TABLE III

Plot	Nitrogenous Material	N in each application. Lbs. per 1000 sq.ft. July 1, 14, Aug. 1	Clover leaves June 28	Clover leaves July 12	Clover leaves July 25	Clover leaves Aug. 11	% decrease June 28 to Aug. 11	Clover leaves Sept. 8	Recovery. Increase in clover leaves Aug. 11-Sept. 8
21	Castor Pomace	1.05	130	120	150	145	-10	155	10
22	" "	4.2	200	205	220	225	-12.5	210	-15
23	" "	2.1	185	125	160	150	19	200	50
24	" "	1.05	85	110	140	150	-76	140	-10
25	" "	4.2	135	120	60	65	51	45	-20
26	" "	2.1	200	170	165	150	25	195	45
27	" "	1.05	130	120	135	135	-4	145	10
28	Uramon	4.2	165	135	50	40	75	10	-30
29	"	2.1	90	100	20	5	94	0	-5
30	"	1.05	75	65	55	30	60	50	20
31	"	4.2	70	70	10	10	85	0	-10
32	"	2.1	140	145	105	85	39	45	-40
33	"	1.05	80	90	85	75	6	55	-20
34	"	4.2	130	100	30	15	88	10	-5
35	"	2.1	200	105	30	20	90	5	-15
36	"	1.05	200	185	150	130	35	110	-20
37	Check	0.	135	155	165	150	-11	125	-25
38	"	0.	135	145	145	120	11	120	0
39	"	0.	135	160	135	120	11	115	-5
40	"	0.	130	155	130	120	8	105	-15

TABLE III

Plot	Nitrogenous Material	N in each application. Lbs. per 1000 sq.ft. July 1, 14, Aug. 1	Clover leaves June 28	Clover leaves July 12	Clover leaves July 25	Clover leaves Aug. 11	% decrease June 28 to Aug. 11	Clover leaves Sept. 8	Recovery. Increase in clover leaves Aug. 11-Sept. 8
41	Check	0	150	120	130	115	23	105	-10
42	"	0	195	185	160	155	20.5	155	0
43	"	0	200	160	150	160	20	180	20
44	"	0	100	90	80	75	12.5	105	30
45	"	0	180	180	145	140	22	155	15
49	"	0	110	100	90	120	-9	125	5
50	"	0	165	145	145	150	3	195	45
46	Complete 5-8-7	4	75	50	30	20	73	25	5
47	" "	4	120	75	25	0	100	0	0
48	" "	4	90	20	5	5	94	5	0

FIGURE II

REDUCTION IN CLOVER LEAVES (AVE. 3 PLOTS) RESULTING FROM APPLICATIONS OF SULPHATE OF AMMONIA AT 3 RATES FROM TABLE III

RATE = POUNDS N. PER 1000 SQ. FT.
CONTROL = AVE. OF ALL CHECK PLOTS

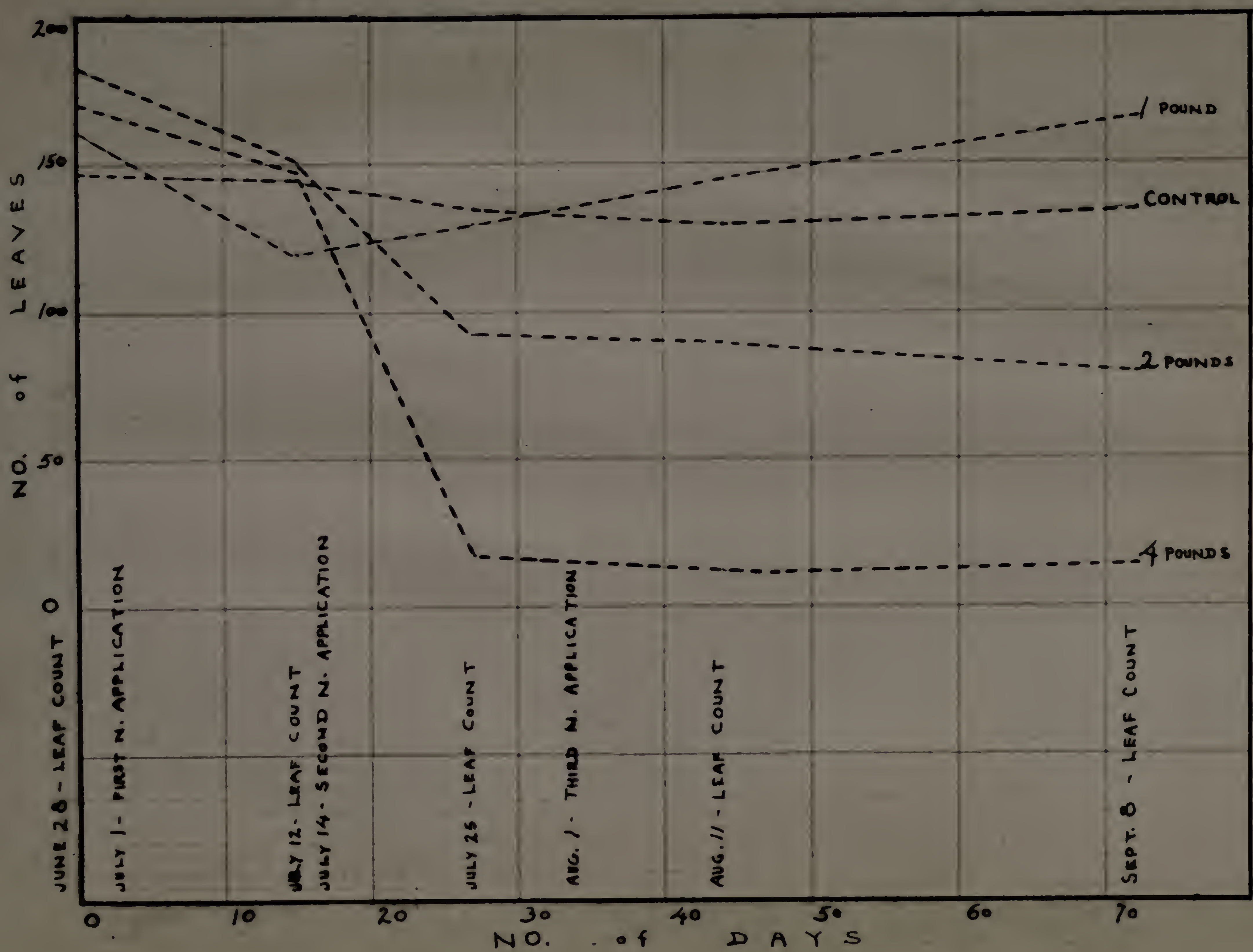


FIGURE III

REDUCTION IN CLOVER LEAVES (AVE. 3 PLOTS) RESULTING FROM APPLICATIONS OF NITRATE OF SODA AT 3 RATES FROM TABLE III

RATE = POUNDS N. PER 1000 SQ. FT.
CONTROL = AVE. OF ALL CHECK PLOTS

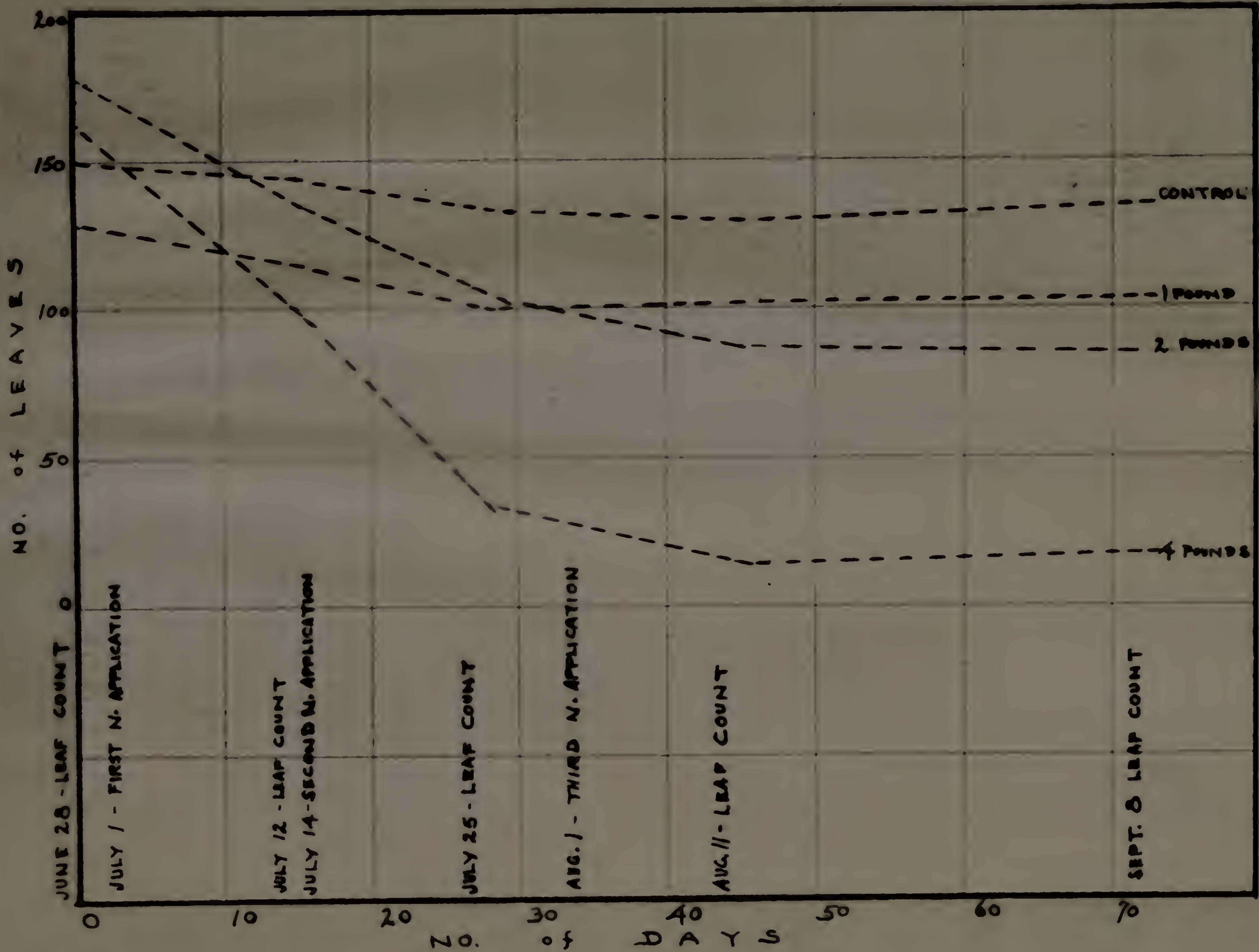


FIGURE IV

REDUCTION IN CLOVER LEAVES (AVE. 3 PLOTS) RESULTING FROM APPLICATIONS OF CASTOR POMACE AT 3 RATES FROM TABLE III

RATE = POUNDS N. PER 1000 SQ. FT.
CONTROL = AVE. OF ALL CHECK PLOTS

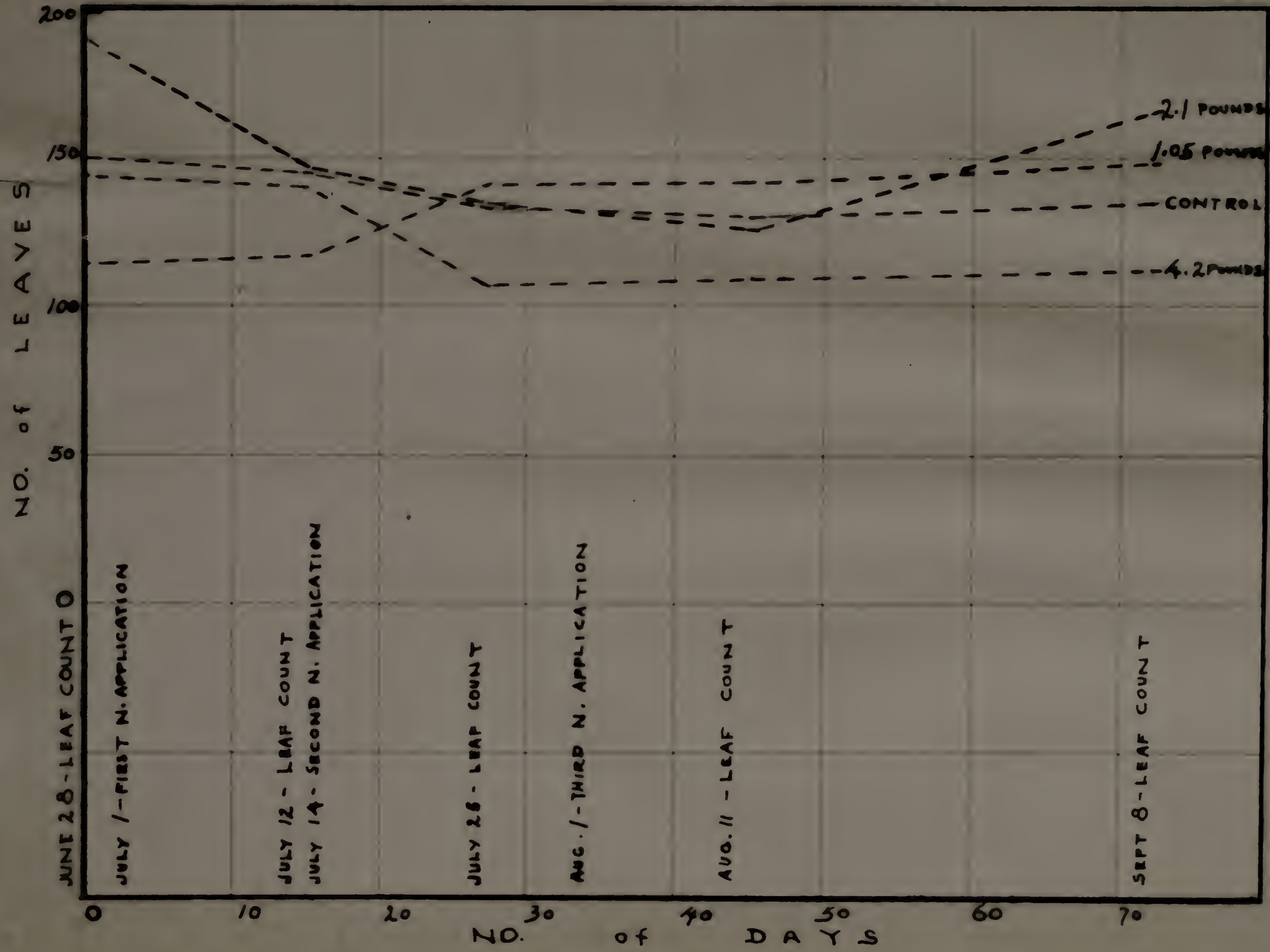


FIGURE V

REDUCTION IN CLOVER LEAVES (AVE. 3 PLOTS) RESULTING FROM APPLICATIONS OF "URAMON" AT 3 RATES
FROM TABLE III

RATE = POUNDS N. PER 1000 SQ. FT.
CONTROL = AVE. OF ALL CHECK PLOTS

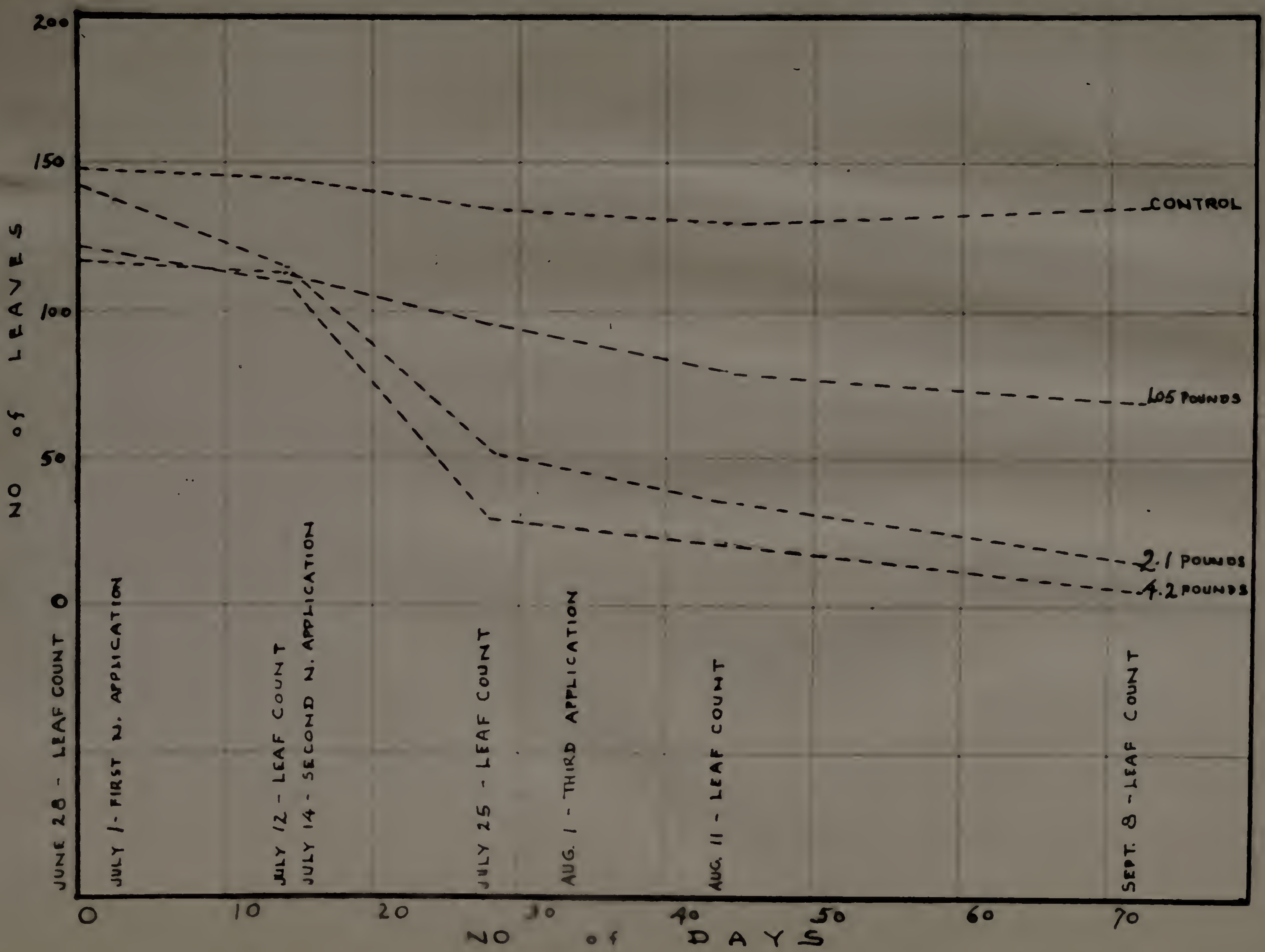
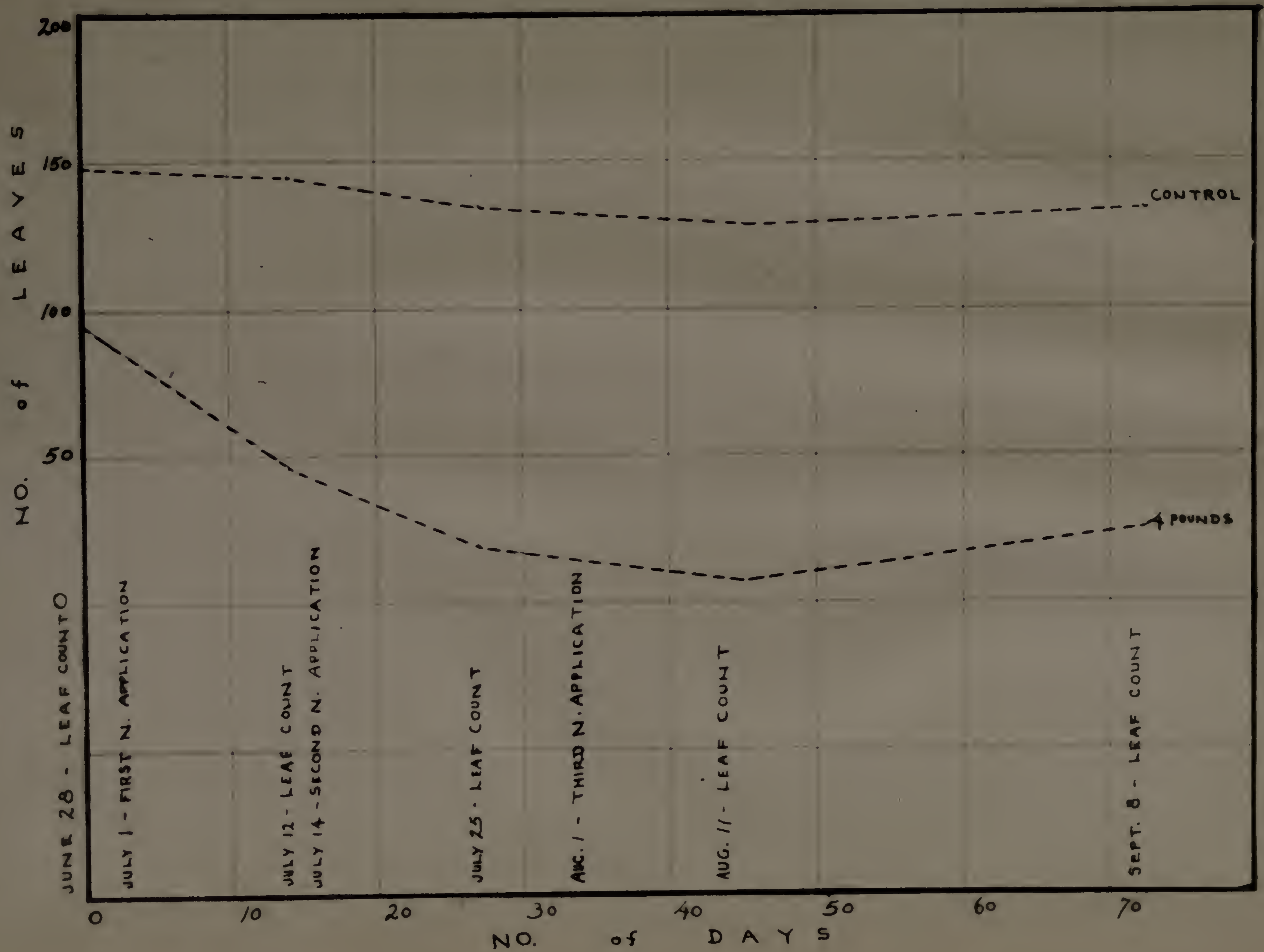


FIGURE VI

REDUCTION IN CLOVER LEAVES (AVE. 3 PLOTS) RESULTING FROM APPLICATIONS OF COMPLETE 5-8-7 FERTILIZER AT 4 RATE FROM TABLE III

RATE = POUNDS N. PER 1000 SQ.FT.
CONTROL = AVE. OF ALL CHECK PLOTS



LITERATURE CITED

1. AHLGREN, H. L. and AAMODT, O. S. Harmful root interactions as a possible explanation for effects noted between various species of grass and legumes. Jour. Amer. Soc. Agron. 31: 982-985. 1939.

2. ALLISON, F. E. Carbohydrate supply as a primary factor in legume symbiosis. Soil Sci. 39: 222-239. 1935.

3. ARNON, D. I. Effect of ammonium and nitrate nitrogen on the mineral composition and sap characteristics of barley. Soil Sci. 48: 295-307. 1939.

4. BARNES, E. E. Effect on permanent pastures of treatments with limestone and acid phosphate as measured by the quantity and quality of vegetation produced. Jour. Amer. Soc. Agron. 16: 241-251. 1924.

5. BEAUMONT, A. B. Experiments with permanent pastures. Mass. Agr. Exp. Sta. Bull. 281. 1932.

6. BLACKMAN, G. E. An ecological study of closely cut turf treated with ammonium and ferrous sulfates. Ann. Appl. Biol. 19: 204-220. 1932.

7. BLACKMAN, G. E. A comparison between the effects of ammonium sulfate and other forms of nitrogen on the botanical composition of closely cut turf. Ann. Appl. Biol. 19: 443-461. 1932.

8. BLACKMAN, G. E. The ecological and physiological action of ammonium salts on the clover content of turf. Ann. Bot. 48: 975-1001. 1934.

9. BLACKMAN, G. E. The interaction of light intensity and nitrogen supply in the growth and metabolism of grasses and clover (Trifolium repens). The effects of light intensity and nitrogen supply on the clover content of a sward. Ann. Bot. 2: 257-280. 1938.

10. BLACKMAN, G. E. The interaction of light intensity and nitrogen supply on the growth and metabolism of grass and clover. IV. The relation of light intensity and nitrogen supply to protein metabolism of the leaves of grasses. Ann. Bot. 4: 533-587. 1940.

11. BLACKMAN, G. E. and TEMPLEMAN, W. G. The interaction of light intensity and nitrogen supply on the growth and metabolism of grasses and clover. II. The influence of light intensity and nitrogen supply on the leaf production of frequently defoliated plants. Ann. Bot. 2: 765-791. 1938.

12. BROWN, B. A. Some factors affecting the prevalence of white clover in grassland. Jour. Amer. Soc. Agron. 31: 322-332. 1939.

13. CANNON, W. A. Physiological features of roots with special reference to the relation of roots to aeration of the soil. Carnegie Inst. Pub. 368: 168-178. 1925.

14. COOPER, H. P., WILSON, J. K., and BARRON, T. H. Ecological factors determining the pasture flora in Northeastern United States. Jour. Amer. Soc. Agron. 21: 607-627. 1929.

15. DODD, D. R. Some factors affecting the content, fluctuation, and distribution of white clover in permanent sod areas in Ohio. Soil Sci. Soc. Amer. Proc. 6: 288-297. 1942.

16. DORSEY, HENRY. The effect of fertilizer treatments upon the quantity and quality of pasture vegetation. II. Nitrogen treatments. Jour. Amer. Soc. Agron. 21: 679-686. 1929.

17. FRED, E. B., WILSON, P. W., and WYSS, O. Light intensity and the nitrogen hunger period in the Manchu soybean. Proc. Nat. Acad. Sci. 24: 46-52. 1938.

18. GARNER, E. S. and DAMON, S. C. The persistence of certain lawn grasses as affected by fertilization and competition. Agr. Exp. Sta. R. I. State College. Bull. 217. 1929.

19. GLÖBEL, C. The relation of soil nitrogen to nodule development and fixation of nitrogen by certain legumes. N. J. Agr. Exp. Sta. Bull. 436. 1926.

20. HARRISON, C. M. Responses of Kentucky bluegrass to variations in temperature, light, cutting and fertilizing. Plant Physiol. 9: 83-106. 1934.

21. HOLLOWELL, E. A. White clover. U.S.D.A. Leaflet No. 119. 1936.

22. HOPKINS, E. W. and FRED, E. B. Influence of various nitrogenous compounds and mannitol on nodule formation by clover. Plant Physiol. 8: 141-155. 1933.

23. HOPKINS, E. W., WILSON, P. W., and PETERSON, W. H. Influence of KNO_3 on nodule formation and N fixation by clover. Plant Physiol. 7: 597-611. 1932.

24. LAURENT, E. Recherches sur les nodorantes radicales des legumineuses. Ann. Inst. Pasteur 5: 105-139. 1891.

25. LOEHWING, W. F. Root interactions of plants. Bot. Rev. 3: 195-239. 1937.

26. Mazé, N. Les microbes des nodosites de legumineuses. Ann. Inst. Pasteur 12: 1-25. 1898.

27. MEYER, B. S. and ANDERSON, D. B. Plant Physiology. D. Van Nostrand Company, Inc. New York. 1948.

28. PARKER, F. W. and TRUOG, E. The relation between the nitrogen content of plants and the function of calcium. Soil Sci. 10: 49-56. 1920.

29. RICH, A. E. and ODLAND, T. E. The effect of various fertilizers on the botanical composition and yield of grass legume hay. Jour. Amer. Soc. Agron. 39: 390-394. 1947

30. ROBINSON, R. R. and SPRAGUE, V. G. The clover populations and yields of Kentucky bluegrass sod as affected by nitrogen fertilization, clipping treatments and irrigation. Jour. Amer. Soc. Agron. 39: 107-116. 1947.

31. SHEAR, C. G., CRANE, H. L., and MYERS, A. T. Nutrient element balance; a fundamental concept in plant nutrition. Proc. Amer. Soc. Hort. Sci. 47: 239-247. 1946.

32. SHIRLEY, H. L. The influence of light intensity and light quality upon the growth of plants. Amer. Jour. Bot. 16: 354-390. 1929.

33. SHIRLEY, H. L. Light as an ecological factor and its measurement. Bot. Rev. 1: 355-371. 1935.

34. SHIRLEY, H. L. Light as an ecological factor and its measurement. Bot. Rev. 11: 497-532. 1945.

35. SPRAGUE, H. B. and EVAUL, E. E. Experiments with turf grasses in New Jersey. N. J. Agr. Exp. Sta. Bull. 497. 1930.

36. STROWD, W. H. The relation of nitrates to nodule production. Soil Sci. 10: 343-356.

37. THORNTON, H. G. The symbiotic relationship between soil bacteria and higher plants as exemplified by leguminosae. Proc. 3rd International Congress Soil Sci. (Oxford Eng.) 2: 81-94. 1935.

38. THORNTON, H. G. The present state of our ignorance concerning the nodules of leguminous plants. Sci. Prog. 31: 236-249. 1936.

39. THORNTON, H. G. and NICOL, H. Reductions of nodule number and growth produced by the addition of $NaNO_3$ to lucerne in sand cultures. Jour. Agr. Sci. 26: 173-188. 1936.

40. VIRTANEN, A. I. The investigation on the root nodule bacteria of leguminous plants. Jour. Agr. Sci. 25: 278-289. 1935.

41. VIRTANEN, A. I. The chemistry of grass crops. Jour. Soc. Chem. Industry 54: 1015-1020. 1935.

42. VIRTANEN, A. I. Mechanism of symbiotic nitrogen by leguminous plants. Proc. Soil Sci. Soc. Amer. 4: 221-222. 1939.

43. WALLACE, A., TOTH, S. J., AND BEAR, F. E. Cation and anion relationships in plants with special reference to seasonal variation in the mineral content of alfalfa. Agron. Jour. 41: No. 2: 66-71. 1949.

44. WILSON, P. W. Symbiotic nitrogen fixation by the leguminosae, Bot. Rev. 3: 365-399. 1937.

45. WILSON, P. W. The carbohydrate-nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bull. 129. 1935.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. Dale H. Sieling, Head of the Department of Agronomy of the University of Massachusetts, for his helpful suggestions; to Professor Lawrence S. Dickinson, Associate Professor of Agrostology, for his helpful suggestions and for providing material for the experiment; to Dr. Mack Drake, Research Professor of Chemistry; to Dr. T. T. Kozlowski, Associate Professor of Botany and to the other instructors of the Department of Agronomy and the Department of Botany for their interest and aid throughout the experiment.

APPROVED BY:

Dale H Sieling

Mack Drake

Theodore T. Kozlowski

Committee on Thesis

DATE 13 April 1950