A STUDY OF THE COMPARATIVE MERITS OF ROCK PHOSPHATES AND SUPERPHOSPHATE ON A GRAIN CROP SEEDED TO A HAY MIXTURE ON THREE MAJOR SOIL TYPES OF THE EASTERN TOWNSHIPS OF QUEBEC, CANADA

By

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AN ABSTRACT

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This problem was concerned primarily with the comparative evaluation of rock and superphosphate, with and without lime, on oats undersown to a mixture of timothy and alfalfa on different soil types. The data were obtained from a greenhouse experiment in which two commercial forms of rock phosphate were tested against ordinary superphosphate.

The two rock phosphates were Aero-phos from Florida and Reno Hyperphosphate from North Africa; and the three soil types, Greensboro loam, Magog stony loam and Sheldon sandy loam, are common to Richmond, Sherbrooke, Stanstead and Compton counties of the Eastern Townships region of Quebec.

Yields of oats, grain and straw were obtained and certain plant characters of the grain crop were measured during the growing period. Hay yields, on the basis of five cuts, were taken from an alfalfa-timothy mixture. After the fifth cut the roots of the alfalfa-timothy mixture were thoroughly washed, oven-dried and weighed.

The data show conclusively the merits of ordinary superphosphate in increasing the yields of oat grain and straw, over Reno Hyperphosphate and Florida Aero-phos.

Certain plant characters of the grain crop, such as the height of plants, the number of leaves, the degree of tillering and the earliness in heading out, showed definitely more improvement with superphosphate treatment than with either of the rock phosphates, attributable to the immediate availability of the phosphorus in superphosphate.

On all soil types, Reno Hyperphosphate, in increasing the oats by 55 percent for all grain yields, and by 22 per cent for all straw yields, proved significantly better than Florida Aero-phos.

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On all soil types, superphosphate plus lime, in increasing the grain and straw yields, proved significantly better than superphosphate alone. The addition of lime to rock phosphates failed to produce significant increases in grain and straw of yields.

Rock phosphates proved definitely superior in increasing the yields of alfalfa-timothy tops and roots, when compared with ordinary superphosphates. The superior merits of Reno Hyperphosphate were manifested in better hay and root yields which were significant, in 33 and 44 per cent, respectively, of all comparisons, over those induced by Florida Aero-phos.

The value of lime at the rate of one and four tons in the production of alfalfa-timothy top and root yields, crystallized in significantly higher yields from the more acid Greensboro and Sheldon soils, when superphosphated or rock phosphated. However, with the high rate of lime, these yields produced on superphosphated Magog soil, the least acid of the three types, lacked significance, and registered a significant decrease with rock phosphate treatments.

Further studies designed to evaluate the merits of rock phosphate-superphosphate combinations are recommended. The results of this study would seem to indicate that rock phosphates complemented with superphosphate may have a place in certain fertility programs in Quebec.

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INTRODUCTION

The marked increase in phosphate fertilizer use in Eastern Canada has emphasized the need of more quantitative and precise information on the phosphorus needs of different soils and the factors affecting the efficient use of different phosphate fertilizers.

Because of the extensive acreage of phosphate deficient soils, the question arises whether there could be an economically justifiable place for rock phosphate in the soil fertility programs of Quebec and Eastern Canada.

In general, crops on the main soil types of the area show a very pronounced response to phosphate fertilization as compared with application of nitrogen and potassium. Grain, legume hay and pasture crops respond markedly to phosphate fertilizers. Recent figures show that hay is the predominant crop in the area due to its importance in dairy and livestock farming, which is the chief agricultural occupation of the Eastern Townships of Quebec. The comparison of phosphate carriers on the establishment and maintenance of alfalfa is of particular interest. As yet it has been impossible to maintain alfalfa stands for more than a year or two but still, every spring, throughout the Eastern Townships of Quebec, thousands of pounds of alfalfa are seeded in ordinary hay mixtures with practically no returns whatsoever.

There have been relatively few publications on the study of phosphate carriers during the past fifteen years. Much of the old data on the comparison of superphosphate and rock phosphates are conflicting and quite inconclusive. More basic information is needed concerning the effect of soils, crops and climatic conditions on the comparative value of different phosphates.

Soil phosphorus problems vary so much in different regions and under different soil, climatic and crop conditions, that generalizations on research needs for a country as a whole have only limited value. For this reason only one phase of the problem was studied specifically for a limited number of crops and on only a few of the major soil types of the area.

This problem was concerned primarily with the comparative evaluation of rock and superphosphate, with and without lime, on oats undersown to a mixture of timothy and alfalfa on different soil types. The data were obtained from a greenhouse experiment in which two commercial forms of rock phosphate were tested against ordinary superphosphate.

Figure I.--The response of oats to superphosphate

The soils of Central Quebec respond markedly to phosphorus. Fertility test on oats in 1954. Plots, left to right, received the following fertilizers: 4-0-12; 4-0-0; 4-24-0.

REVIEW OF LITERATURE

General Review

During the past fifteen years especially, marked advances have been made in the knowledge of phosphorus reaction in soils with the result that the literature on the subject has been very extensive. The present review of literature is limited to the more pertinent aspects of this problem.

Previous investigators report no definite agreement on the merits of rock and superphosphate. When compared with superphosphate, rock phosphate showed up relatively well in a number of studies, Bartholomew (2), Noll and Irvin (23), Smith (34), Weeks and Miller (41), and not so well in a number of others, Frear (12), Gilbert and Pember (15), Roberts (28), Salters and Barnes (29), Wiancko *et al*. (43). This suggests that conditions where rock phosphates can be used successfully may be somewhat more specific than for most other fertilizer materials.

McKenna (21), in a recent study in South Africa, tested mixtures of superphosphate and rock phosphates against superphosphate alone. The tests were conducted on acid soils, high in aluminum and iron and under high rainfall conditions. These conditions, incidentally, are analogous to those in the Eastern Townships of Quebec. The South African worker found that a mixture of three parts of superphosphate and two parts of finely ground rock phosphate gave yields similar to those from an equal amount of superphosphate, and that mixtures showed advantages over superphosphate in reversion, physical conditions and ease of handling. The South African farmers are now using well over 20,000 tons of mixtures of superphosphate and rock phosphates annually.

It is important, in evaluating different phosphate fertilizers, to take into account both the immediate and residual effects as suggested by Frear (12). The more soluble phosphates, such as superphosphate, exert their maximum effect immediately, whereas the less soluble fertilizers, such as phosphate rock, may exert a more or less constant effect for several years or become slightly more available with time, as mentioned by Roberts (28) and other workers. Such an increase might be expected on the basis of the greater amount of phosphorus generally added in the rock, if the phosphorus shows any noticeable availability a few years after it has been added.

The Effect of Phosphate Fertilizer on Soil Reaction

The effect of fertilizers on the reaction of the soil has long attracted the attention of many investigators. Such materials as sodium nitrate and calcium cyanamide are known to leave basic residues, while ammonium sulphate and potassium chloride have been found to leave acid residues in the soil. The results of studies on the effect of phosphate fertilizers on the reaction of soils, however, have been quite variable. A slightly higher pH reading for the soil due to additions of superphosphate was reported by Harrison (17) and by Sewell and Latshaw (32). On the other hand, Skinner and Beattie (33) and Snider (35) found an increase in acidity following its use, while Hance (16) and Jensen (18) noted no change in the reaction of the soil.

In some cases rock phosphate appeared to have a neutralizing effect on acid soils, Snider (35) and Thor (38), but Brown (5) and Pierre (26) noted no such effect.

The claim has been made that rock phosphate can take the place of lime in acid soils. Rock phosphate may supply calcium as a plant nutrient and it may neutralize some of the soil acidity but, because of the difficulty of separating the nutritional effects of calcium-bearing materials from their neutralizing powers, investigators have been doubtful of the relative importance of the two functions. Peterson et al. (24) found that a 500 pound per acre application of finely ground rock phosphate produced a slight decrease in the acidity of one particular soil but their study of several soil types showed quite a variation between soil types in the effect of different phosphate fertilizers on soil reaction.

The Effect of Lime on Phosphate Availability

An extensive literature review indicates that the availability of all nutrients obtained by plants from the soil is influenced to some degree by the level of lime present. The application of lime influences the quantity of available phosphorus in soils according to many workers. This fact was borne out both by laboratory analyses and field experiments.

Truog (39) stated that at pH 6.5 calcium bicarbonate becomes sufficiently abundant in the soil solution to keep a considerable portion of the phosphorus in the form of calcium phosphate, which is soluble in carbonic acid and, therefore, readily available to crops. This applies to both the phosphorus naturally present in soils and that provided in the form of manures and fertilizers.

When lime is present or added in sufficient quantity to raise the pH beyond 7.5, the influence on phosphate availability gradually becomes less favorable, but this is not serious until the pH goes beyond 8.0 and there is present 2 to 3 per cent or more of free calcium carbonate. Truog explains this by the following reactions:-

$$CaCO_3 + H_2CO_3 \rightleftarrows Ca(HCO_3)_2$$

$$Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftarrows Ca_2H_2(PO_4)_2 + Ca(HCO_3)_2$$

The first reaction shows the action of carbonic acid on calcium carbonate and the second reaction shows the action of carbonic acid on calcium phosphate. If there is sufficient calcium carbonate present, the action of carbonic acid on it will create a soil solution saturated with calcium bicarbonate which will greatly retard, or even stop, the second reaction as it also produces calcium bicarbonate. In other words, in the face of a saturated condition, all reactions involving the formation of the product are brought to a standstill until some of the product is removed by leaching or plant feeding. This explanation is in consonance with the well-known principle of chemistry usually referred to as the law of mass action.

Truog (39) maintained that plants which require large amounts of calcium remove the soluble calcium salts at a rate sufficiently rapid to allow the accumulation of phosphate to continue. Therefore plants utilizing large quantities of calcium are considered to be strong feeders of rock phosphate. On the other hand, plants which are low in calcium requirement quickly allow an accumulation of $Ca(HCO_3)_2$ to a point of saturation, after which further solution of the phosphate is very slow.

Cook (7) reported that the addition of lime to soils caused significant increases in the amounts of readily available soil phosphates. Sewell and Latshaw (32) observed that fertilization with superphosphate did not increase the percentage of phosphorus in alfalfa but that application of lime with superphosphate produced the opposite result. Davis and Brewer (11) pointed out that liming soils low in calcium content enabled winter legumes to utilize larger quantities of the phosphorus supplied by superphosphate.

However, very little is known of the precise nature of the transformation process and also of the type of phosphorus compounds that contribute towards the increased availability. Some investigators entertain the opinion that a part of the iron and aluminum phosphates becomes soluble by chemical interaction with lime while, according to others, the availability of phosphorus is due to the mineralization of organic phosphorus compounds in the soil.

Since, as found by Ghani and Aleem (14), acid soils are frequently characterized by high accumulation of organic phosphorus and also by a large percentage of iron and aluminum phosphates, transformation of one or both of these types of compounds seems to be the most probable thing to happen during the process of conversion. The change in the soil reaction brought about by lime is a fundamental factor in both these kinds of transformation.

It is known that native and soluble phosphates applied as fertilizers remain more readily available when the pH of the soil is about 6.5 or higher (barring a great excess of calcium carbonate), and that rock phosphate is usually more effective when the soil is at least slightly acid. On the more acid soils, the phosphate rock is more soluble and is frequently equal or superior to the superphosphate, according to Salter and Barnes (29) and Wiancko et al. (43). In certain cases yields are depressed by lime with rock phosphate as compared with rock phosphate alone, but in other cases yield increases have been attributable to lime and superphosphate.

Cook (7) maintained that, although an increase in base saturation of soils lowered the immediate availability of rock phosphates to crops like corn and oats, it tended to keep the native soil phosphates and those added as soluble salts in the form of calcium phosphate rather than as less available basic iron phosphates.

It is well established that the use of excessive amounts of lime on certain soils may cause detrimental effects on plant growth, at least temporarily. Mann (20) and Pettinger, Henderson and Wingard (25) claimed that these were due to a lack of soluble manganese. Karraker (19) and Pierre and Browning (27) found that liming had a delayed effect. The immediate effects of liming, particularly in excessive amounts, may be entirely different, as far as the availability of phosphate to plants is concerned, from the ultimate effect. Plants grown on soils, to which large amounts of liming materials have recently been added, may show symptoms of phosphate starvation and respond markedly to high phosphate fertilization.

Schmehl et al. (30) expressed the opinion that the poor growth associated with acid soils was a complex function of many contributing factors.

The Effect of Organic Matter on Phosphate Availability

Many investigations during the last eighty years have shown that only 10 to 20 per cent of applied phosphate is utilized by crops and that the rest is fixed in a form not readily available. The process of phosphate fixation has received considerable attention and many theories have been advanced in explanation.

Copeland and Merkle (9), Gerretsen (13) and Midgley and Dunklee (22) observed that organic matter increased the availability of soil phosphate and rock phosphate, when added to the soil as fertilizer. Struthers and Sieling (36) and Swenson *et al.* (37) presented evidence of the pronounced effectiveness of many organic substances commonly found in soils in preventing the precipitation of phosphate by iron and aluminum between pH values of 3 to 9. Dalton *et al.* (10) have recently attributed this effect of organic matter to the ability of certain metabolic products of microbiological decomposition to form stable complex molecules with iron and aluminum

MATERIALS AND METHODS

Soils and Treatments

Two commercial forms of rock phosphate were tested against ordinary superphosphate in this study. The two rock phosphates were Aerophos from Florida and Reno Hyperphosphate from North Africa. Detailed analyses of these two phosphates are given in Tables 1 and 11.

The three soil types under study, namely, Greensboro loam, Magog stony loam and Sheldon sandy loam, are common to Richmond, Sherbrooke, Stanstead and Compton counties of the Eastern Townships region of Quebec. The soils of this area lie in the climatic belt which favors the development of podsols.

Greensboro loam, when cultivated, has a dark brown surface soil. This soil type is developed on glacial till which is found at an average depth of from 30 to 36 inches. The smooth, rolling topography and its good physical condition make the Greensboro loam suitable for a wide variety of crops. In general the soil is well supplied with phosphorus but it is usually difficultly available. Under field conditions there is enough gravel in this soil to keep it fairly open and ensure good drainage; yet 80 to 90 per cent of the gravel free soil is silt and sand which impart a good moisture-holding capacity, giving at the same time satisfactory internal drainage.

Magog stony loam, like Greensboro loam, is developed on glacial till. When cultivated it develops a distinctly characteristic greyish white appearance on the surface, visible from a considerable distance. The topography varies from level to undulating. The drainage is usually very poor owing to a very stony, compact layer close to the surface. The soil under the compact layer is quite friable and loose but tends to become very compact soon after cultivation and, despite its moderate fertility, has apparent physical problems.

Sheldon sandy loam, according to Cann and Lajoie (6), is developed from fluvial glacial material deposited on lacustrine clay. The drainage is good and the soil responds readily to fertilization. Great care must be taken in soil management and crop planning as this soil type is easily subject to erosion even on fairly smooth topography.

Greenhouse Procedure

Surface soils which had been under cultivation for at least twenty years were used for the greenhouse studies. Trash and stones were removed from the soils by sifting them through a one-half inch screen after they had been dried and mixed. The soils were then transferred to one-gallon glazed pots where drainage was provided through a side opening near the bottom. The soils were measured on a volume basis, id. est, for each soil type the weight of that volume of soil required to fill a pot was obtained, and the remainder of the pots for that soil type were filled with equivalent quantities of soil by weight.

All treatments were replicated three times, and the pots within each replication were randomized. An effort was made to reduce the effects of light and temperature variations in the greenhouse by a weekly reshuffling of the cultures within each replication. Entire replicates were also rotated at weekly intervals.

The treatments are shown in Table 1. Nitrogen and potassium requirements, for all cultures, were satisfied by the application of 200 pounds of nitrate of soda (16% N) and 200 pounds of muriate of potash (50% K_2O) per acre, at the beginning of the experiment. Deficiencies of nitrogen and potassium were checked periodically by means of plant tissue tests after the method of Cook (8). All cultures received minor elements in sufficient quantities to supply the Mg., Bo., Cu., Mn. and Zn. needed. The mixture of trace elements was applied to the oat seedlings shortly after the grain was up, at the following rates per acre:

125 lbs. $MgSO_4$
50 lbs. $Na_2B_4O_7 \cdot 5H_2O$
50 lbs. $MnSO_4$
15 lbs. $CuSO_4$
15 lbs. $ZnSO_4$

The fertilizers were applied to the soil in the pots in a layer at a two-inch depth. In the case of treatments which contained lime, the lime was thoroughly mixed with the top five inches of soil before the fertilizer was added.

Immediately after the addition of the fertilizers, Roxton oats were seeded at a one-inch depth, and alfalfa and timothy at a one-half inch depth. Rates of seeding were 14 seeds of oats, 30 of timothy and 8 of inoculated alfalfa. Later the crop was thinned to 7, 15 and 4 per culture of oats, timothy and alfalfa, respectively. In the thinning operation a special effort was made to remove the entire plant.

All cultures were checked daily for the need of water and the plants were watered with a fine spray whenever water was required. An effort was made to maintain a night temperature of 50° F. During the winter months the length of day was increased by the use of artificial lights to simulate the normal length of day required. For example, oats seeded November 1 in the greenhouse received 4.7 additional hours of artificial light per day for the month of November which was comparable, on the basis of hours of sunshine, to the month of May at the Lennoxville Experimental Farm. For December 5.1 hours of artificial light were added to parallel the number of hours of sunshine for June, etc. Insects were controlled with Benzo-fume and Loro insecticide.

Measurements of certain plant characters of the grain crop were obtained during the growing period. The following plant characters were measured:

(a) Height of oat plants after 30 and 60 days' growth

(b) Number of oat leaves after 30 and 60 days' growth

(c) Degree of tillering in oats after 30 and 60 days' growth

(d) Earliness in heading out of oats

(e) Height of oats at harvest time.

These measurements were calculated on the basis of the entire population of oat plants. In the case of measurements of the height of oat plants after 30 and 60 days' growth, 410 measurements for each soil type were required. This number was greatly increased for the measurements of the number of leaves after 30 and 60 days' growth.

The grain crop was harvested starting on June 9, 1953. There were slight differences in the dates of maturity on the three soil types. Both oat grain and straw were thoroughly oven dried at 212° F and weighed to the nearest tenth of a gram. Samples were left in the oven until complete dryness was assured and weighings were made immediately after removal from the oven. The alfalfa-timothy hay plants were cut when the alfalfa was 10 per cent in bloom. Five cuts were gathered between July 31, 1953, and March 17, 1954, the dates of the first and fifth cuts. The forage samples also were oven dried and weighed in the same manner as the oat grain and straw.

Root Washing Procedure

The following method was used for washing the roots of the alfalfa-timothy plants. Right after the last cut of hay, cultures containing the samples were soaked for several hours. During the washing process the force of a coarse spray of water and some rubbing were sufficient to break up all lumps of soil. The washing was done in a low rectangular wooden box as shown in Figure VII. This box was divided into two sections with a medium-coarse screen in the partition between the two sections. The water outlet on the bottom of the small section of the box was covered by a fine screen. After a thorough soaking, the roots were first washed in the large section with a coarse spray. Washing was continued until practically all soil was removed from the first compartment, and such soil as did remain was free of root fiber. The roots and root fiber, freed in this way, collected on the screens and were transferred to fine mesh circular screens where they were cleaned again. A forceful spray of water was used a second time to loosen soil particles, and then the roots were placed in a metal pan containing three or four inches of water. Here the roots were washed by gentle manipulation, and the root fiber floating on the water was removed and later added to the rest of the roots for total root weight. It was frequently necessary to repeat the washing by manipulation and the collecting of the root fiber. The crowns of alfalfa and timothy plants were separated from the roots. Finally the samples were dried in an oven held at a temperature of 212° F for approximately five hours. As soon as the containers had cooled sufficiently to permit handling, the absolute dry weight was determined to the nearest tenth of a gram.

Chemical Analysis Procedure

The pH values were obtained with a Leeds and Northrup pH meter using a soil : water ratio of 1 : 2.5. Exchangeable bases (calcium, magnesium, potassium) were determined on an ammonium acetate extract as given in Chemical Methods of Soil Analysis (1). Exchangeable hydrogen was obtained by leaching the soil with ammonium acetate and then titrating the leachate to the original pH of the ammonium acetate solution as determined by a glass electrode. The method used was essentially that described by Schollenberger and Simon (31). The sum of the exchangeable cations (calcium, magnesium, potassium, hydrogen) was taken as the base exchange capacity. The values reported for adsorbed phosphorus were obtained by the laboratory technique given by Bray and Kurtz (4).

RESULTS

Influence of Phosphates on Oat Yields

Table 2 shows the grain yields as influenced by superphosphates and rock phosphates, with and without lime, on the three soil types studied, and that the highest yields were obtained from superphosphated soils.

On Greensboro loam, with a pH of 5.4, superphosphate, in increasing the grain yields, proved significantly better than Florida Aero-phos in the one and four-ton lime series, or Reno Hyperphosphate with four tons of lime.

The increase in oat grain yields on Magog stony loam, with a pH of 6.6, was significant in favor of superphosphate over Reno Hyperphosphate with all treatments, but these yields lacked statistical significance over those ascribable to Florida Aero-phos in the no-lime cases.

The oat grain yields produced on superphosphated Sheldon sandy loam (pH 5.1), the most acid soil, were significantly greater than those resulting from the fertilization of this soil with either of the rock phosphates.

Figure XV graphically delineates consistently higher grain yields from the three superphosphated soils, than those obtained from these soils when treated with Florida Aero-phos or Reno Hyperphosphate. In most cases Reno Hyperphosphate brought about heavier grain yields than Florida Aero-phos, especially on Sheldon sandy loam.

The straw yields of oats, as presented in Table 3, followed trends similar to those of the grain yields, but which were more pronounced in favor of ordinary superphosphate. Superphosphate produced statistically significant increases in straw yields over rock phosphates on the three soil types under all treatments, except Greensboro loam in the one-ton lime series and Sheldon sandy loam in the no-lime series. The straw yields are graphically presented in Figure XV. It is interesting to note that lime treatments augmented the grain and the straw yields on the three soils.

Figure XV demonstrates grain and straw yields of oats as influenced by superphosphate and rock phosphates, with and without lime, on the three soil types. There was no doubt as to the superiority of superphosphate in increasing both oat grain and straw yields. The addition of lime to superphosphate augmented the grain and the straw yields under all treatments, on the three soil types, with only one exception, namely, a slight reduction in straw yields on Greensboro loam in the one-ton lime series.

The Influence of Phosphates on Various Growth Characters of Oats

The growth characters of the oat plants ascribable to phosphate carriers on the three soil types have been outlined under the heading "Materials and Methods." Reference is made to Figures XV to XX inclusive for a graphic presentation of the effect of the treatments on plant characters.

The height of plants, the number of leaves and the degree of tillering, as measured after 30 and 60 days' growth, emphasize the superior merits of superphosphate when compared with either of the rock phosphates, in increasing these growth characters. According to Figures XVI, XVII and XVIII, liming contributed to a degree to the better utilization of superphosphate. An addition of four tons of lime to either of the rock phosphates, (treatments 9 and 10), depressed the height of plants, the number of leaves and the degree of tillering. Under each treatment the three soil types responded similarly with only slight differences in plant characters.

Superphosphate with four tons of lime (treatment 8) increased substantially the number of leaves between the 30 and 60 day growth periods. On the other hand, rock phosphate treatments (9 and 10) caused much smaller increases in the number of leaves between the 30 and 60 day growth periods. Figures II, III and IV indicate the extent of the increases in the number of leaves and height of plants after 60 days' growth.

Considerable interest was evinced in the very definite improvement in the tillering under superphosphate treatments as shown in Figure XVIII. After 60 days of growth all plants treated with superphosphate had developed tillers while the check plants treated only with (NK) had failed completely to do so. (Compare treatments 1 and 2 for each soil type.) This interesting property of phosphorus would seem to point the way to an important role for the phosphate carriers in grassland farming, predicated of course on their ability to induce the tillering of grasses just as much as apparently they do in the case of grain. Rock phosphates were inefficient in the production of tillering, particularly with high applications of $CaCO_3$ as indicated by treatments 9 and 10.

Figure XIX shows that the early heading of oats was referrable to superphosphate. Applications of lime with superphosphate apparently had very little influence on the early heading out of oats on Greensboro loam and Magog stony loam. But the most acid soil type, namely, Sheldon sandy loam, seemed to profit from a four-ton application of $CaCO_3$ with superphosphate, which reduced the heading out of oats by approximately ten days. (Compare treatments 2 and 8.) The earliness in heading out of grain is an important aspect to consider under Eastern Townships conditions where an early September frost is not uncommon.

The influence of treatments on the height of oat plants at harvest time is shown in Figures VI, VII and XX. Ordinary superphosphate exerted a much more pronounced influence than that of either of the rock phosphates on the height of oats. Under superphosphate treatments with high or low rates of lime, Greensboro and Magog soils showed slight increases in the height of oats, but on Sheldon sandy loam this increase was more pronounced. Rock phosphate applications were less influential, notably with four tons of lime.

Influence of Phosphates on Alfalfa-Timothy Hay Yields

The total yields of alfalfa-timothy hay as influenced by phosphate carriers, after five cuts, are given in Table 4. Table 5 presents the yields by cuts.

On Greensboro loam, Reno Hyperphosphate and Florida Aero-phos, in increasing hay yields, proved significantly better than ordinary superphosphate for all treatments. There was very little to choose between the performance of the two rock phosphates on this soil type. Figure IX shows a pronounced growth increase in the hay of the first cut, due to the addition of one ton of ground limestone to superphosphate. (Compare cultures 38 and 57.)

Both rock phosphates on the slightly acid Magog stony loam caused significant increases over the yields induced by superphosphate with all treatments, except treatment 10. With a four-ton rate of lime, there was a statistically significant reduction in the hay yields from this soil, with the three phosphate carriers, which was even more pronounced where the rock phosphates had been applied. (See Figures VIII and XXI.)

Reno Hyperphosphate with one ton of lime gave the only increase in hay yields on Sheldon sandy loam, which yields were significant over those referred to superphosphate and Aero-phos, as shown in Figure XXI. The four-ton rate of lime reduced the hay yields from all phosphated cultures, compared with the yields obtained from this soil under the one-ton treatment of lime.

The yields of hay by cuts of the three soils, as presented in Table 5, indicated that, although they differed between cuts, the trend of all phosphatic treatments remained quite similar within each cut.

Influence of Phosphates on Alfalfa-Timothy Root Yields

Table 6 gives the weights of roots of alfalfa-timothy hay plants as influenced by superphosphate and rock phosphates, with and without lime, on the three soils. The root weights are also expressed graphically in Figure XXII. A comparison of Figures XXI and XXII shows similar trends for the yields of top and root growths of an alfalfa-timothy mixture, and that the root weights were less affected than the hay yields by applications of lime.

With all treatments heavier yields of hay were obtained from Magog than from Sheldon soil; yet Magog soil gave alfalfa roots of smaller weights than Sheldon. A probable explanation of these differences may be derived from the data in Table 13 showing the pH of these two soils under different treatments.

The roots from Greensboro loam treated with either of the rock phosphates increased significantly in weight over those obtained from this soil when superphosphated. On a comparative basis with Reno Hyperphosphate, Florida Aero-phos with one ton of lime produced significantly heavier roots and, with four tons, it promoted yields which were superior, though not statistically significant.

On Magog stony loam, the least acid soil, both rock phosphates with the low rate of lime proved just about equally effective in root production but, in the no-lime series, Florida Aero-phos registered a significant gain over Reno Hyperphosphate. With all treatments, excepting the four-ton application of lime, both rock phosphates were superior to superphosphate. With four tons of lime, the heaviest roots were produced by Reno Hyperphosphate, superphosphate and Florida Aero-phos, in this order.

Figures X, XI and XII show the response of individual alfalfa roots to phosphate carriers on Magog soil. Figure X demonstrates the more extensive root system of alfalfa on this soil type with rock phosphates as compared with superphosphate. According to Figure XI, additions of lime to Reno Hyperphosphate failed to augment the growth of alfalfa roots while, in Figure XII, it can be noted that applications of lime to Florida Aero-phos depressed this character.

Alfalfa roots grown in Sheldon soil, under all treatments, fertilized with either of the rock phosphates, showed statistical significance over those produced when superphosphate was applied. The property of rock phosphates to promote a greater root system of alfalfa on Sheldon sandy loam is demonstrated by Figure XIII. On this soil this crop gave roots whose weights were significantly in favor of Reno Hyperphosphate over Florida Aero-phos.

Nodulation in all three soils appeared to be more numerous with rock phosphate than with superphosphate fertilization, but no means could be found to establish a basis for comparison.

Influence of Phosphates on the Ground cover of an Alfalfa-Timothy Hay Mixture

Tables 8, 9 and 10 list in detail the ground cover of the components of a hay mixture during their period of production as influenced by the different treatments on the three soil types. The data show a gradual decrease in the ground cover of timothy and a corresponding increase in the stands of alfalfa. Estimations of ground cover were made prior to the first, third and fifth cut of hay. In general, rock phosphates when compared with superphosphate caused considerable percentage increases of alfalfa ground cover, but these increases lacked statistical significance. With one and four tons of ground limestone per acre, added to each of the phosphate carriers, the percentages of the ground cover of alfalfa on the Greensboro and Sheldon soils registered increases over those in the no-lime series.

Table 7 shows the percentage increases in ground cover over, or decreases from, the check treatment, for timothy and alfalfa plants on the three soils. A comparison of the ability of rock phosphates with that of superphosphate to induce alfalfa ground cover points out only one instance where the rock phosphates failed to produce an increase. This exception occurred on Magog stony loam (treatment 10) which, under Florida Aero-phos treatment and with four tons of lime, had a reduced stand of only 9.4 per cent.

Chemical and Physical Composition of Soils

Table 12 expresses the physical and chemical analyses of Greensboro, Magog and Sheldon soils. In Table 13 are shown the initial pH of the soils, the pH values resulting from the treatments and those obtained after the fifth cut of hay, just prior to the washing of the roots.

There was an increase in the pH readings of the soils in the check treatments, attributable to a slight neutralizing value of the water used in the greenhouse for this experiment. Although the initial pH readings of Greensboro and Sheldon soils were 5.4 and 5.1, respectively, the influence of four tons of lime leveled off the difference and brought about quite similar pH readings.

Greensboro loam possessed the highest potential fertility of the three soils and had the highest values for organic matter, base exchange capacity and adsorbed phosphorus.

DISCUSSION

The Influence of Phosphates on Oat Yields and Plant Growth Characters of Oats

The data show conclusively the superiority of ordinary superphosphate in increasing the yields of oat grain and oat straw, when compared with Reno Hyperphosphate and with Florida Aero-phos under the conditions of the experiment. These findings are in agreement with those of many workers including Frear (12) and Roberts (28) who contend that a more soluble phosphate, such as superphosphate, exerts its effect sooner after fertilization than the less soluble rock phosphates.

In other workers' comparative tests with superphosphate and rock phosphates the same rates of total P_2O_5 were used, which meant that the rock phosphates provided much less available citrate soluble P_2O_5. Under the conditions of this experiment identical rates of P_2O_5 were used for all phosphate carriers, calculated on a readily available citrate soluble P_2O_5 basis. The rock phosphates held additional reserves of P_2O_5 because of their high total P_2O_5, as compared with superphosphate which held all its P_2O_5 on a readily available citrate soluble basis.

The lower yields obtained for oat grain and oat straw under the rock phosphate treatments may be explained to a degree by the contentions of Cook (7) and Truog (40). These workers stated that oats, like corn and millet, is a low feeder of calcium and is capable of taking up a higher proportion of phosphorus to calcium than exists in rock phosphates. As already mentioned in the review of literature, there is a gradual accumulation of calcium bicarbonate which, in excess, suppresses the utilization of soluble phosphate. In this study the oat yield results and the trends of oat growth characters appeared consonant with this reasoning, id. est, under rock phosphates the yields and trends for oats were suppressed, as compared with the results produced by ordinary superphosphate. Although no review of literature was available on the influence of phosphate carriers on plant growth characters, it was only reasonable to expect a corresponding reduction in growth characters with a reduction in crop yields.

The graphical presentation of oat yields and oat growth characters, as shown in Figures XV to XX inclusive, is in agreement with the comments by Cook (7) in his review of literature. He stated that in certain cases lime with rock phosphate depressed yields, when compared with rock phosphates alone, while the opposite result was obtained with lime and superphosphate. Figures XV to XX inclusive indicate that, in general, the yields of oat grain and straw were depressed by lime and rock phosphate applications, and that these yields were increased by lime with superphosphate.

Truog (40) reported that when lime was present, or added, in amounts sufficient to raise the pH beyond 7.5, the influence on phosphate availability gradually became less favorable, and that this was not serious until the pH went beyond 8.0. The pH values for phosphate treatments applied to the three soils are given in Table 13. In several cases the pH values for treatments 8, 9 and 10 approached or were beyond 7.5, and in the case of Magog stony loam the pH values reached approximately 8.0. This condition resulted in low yields of oat grain and oat straw on the Magog soil, especially with the rock phosphates (treatments

9 and 10). Treatment 8, superphosphate, was an exception and maintained high yields of grain and straw at a pH of 8.0.

The pronounced increase in the tillering of oats attributable to superphosphate should be considered in the fertilization of oats for hay or pasture. It might even be applicable to grassland farming on the phosphorus deficient soils of Central Quebec when viewed in the light of its property to induce tillering. Possibly another aspect of the merits of superphosphate deserving of attention for this area where the growing season is very short, is its beneficial effects on the early heading out of grain.

The Influence of Phosphates on Alfalfa-Timothy Hay and Root Yields

Truog (40) maintained that plants which required large amounts of calcium removed the soluble calcium salts at a rate which allowed the accumulation of phosphate to continue. Crops like alfalfa, sweet clover and sugar beets, which require large amounts of calcium, are considered strong feeders on phosphorus from rock phosphate. The data in Table 4 and in Figure XXI, expressing total yields of alfalfa-timothy hay after five cuts, point out the same fact. Rock phosphate treatments produced higher yields of hay than superphosphate in all cases except two instances. The yields of roots, as presented in Table 6 and in Figure XXII, gave similar results, and the trends were almost identical for the hay yields except that the lime treatments were less effective.

Obviously there was some overliming injury on Magog soil, as reflected in the hay yields for treatments 8, 9 and 10 and depicted graphically in Figure XXI. The lime treatments raised the pH values to approximately

8.0, indicated in Table 14. Pierre and Browning (27) observed that overliming injury occurred on alfalfa when the pH values were brought to neutrality. They found that the injury was more apparent in the early cuts of hay and that it did not persist much after the third cut of hay. In this study the observations were based on a total of five cuts of hay, and the injury could have been residual from early cuts. There were no reductions in yield due to overliming on Greensboro loam and only slight reductions on Sheldon sandy loam when both of these soils were brought to a pH of approximately 7.4. Figure VIII is a good example of overliming injury on Magog soil but Figure IX presents no depression under high rates of lime on Greensboro loam.

The Fertility of the Soils

Greensboro loam, Magog stony loam and Sheldon sandy loam evidenced marked variations in both the chemical and physical properties as presented in Tables 12 and 13.

In general the crop yields were in direct relation to the fertility levels of the soils, the highest crop yields having been gleaned on Greensboro loam which possessed the highest organic matter, base exchange capacity and absorbed phosphorus of the three soils.

The high gravel content of Magog soil retards its productivity under field conditions but this characteristic was not a limiting factor under greenhouse conditions where controlled watering was maintained.

TABLE 1

FERTILIZER TREATMENTS

	Treatment[1]	Available P_2O_5 per acre per year
1	Check (NK)	--
2	Superphosphate (20% available P_2O_5)	40
3	Reno Hyperphosphate (11% available P_2O_5) (27.5% total P_2O_5)	40
4	Florida Aero-phos (3.75% available P_2O_5) (35.0% total P_2O_5)	40
5	Same as treatment 2 with 1 ton $CaCO_3$	40
6	Same as treatment 3 with 1 ton $CaCO_3$	40
7	Same as treatment 4 with 1 ton $CaCO_3$	40
8	Same as treatment 2 with 4 tons $CaCO_3$	40
9	Same as treatment 3 with 4 tons $CaCO_3$	40
10	Same as treatment 4 with 4 tons $CaCO_3$	40

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. muriate of potash (50% K_2O).

TABLE 2

YIELDS OF OAT GRAIN AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(absolute dry yield in grams, average of three cultures)

Treatment[1]	Soil Type		
	Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
1 Check (NK)	9.0	4.3	7.0
No-lime series			
2 Superphosphate	12.9	10.8	12.9
3 Hyperphosphate	12.4	9.5	11.5
4 Aero-phos	10.6	9.8	10.4
Lime series (1 ton)			
5 Superphosphate	14.7	14.7	15.4
6 Hyperphosphate	13.8	4.4	10.5
7 Aero-phos	11.4	6.2	9.2
Lime series (4 tons)			
8 Superphosphate	17.0	15.5	15.9
9 Hyperphosphate	13.8	5.2	9.9
10 Aero-phos	12.9	5.0	10.3
L.S.D. at 5% level	1.6	1.2	0.9

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 3

YIELDS OF OAT STRAW AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(absolute dry yield in grams, average of three cultures)

Treatment[1]	Soil Type		
	Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
1 Check (NK)	15.3	8.2	15.3
No-lime series			
2 Superphosphate	22.0	18.6	19.6
3 Hyperphosphate	17.6	15.1	17.2
4 Aero-phos	14.3	16.4	18.2
Lime series (1 ton)			
5 Superphosphate	19.5	21.2	22.6
6 Hyperphosphate	17.6	11.1	17.2
7 Aero-phos	16.6	10.9	15.8
Lime series (4 tons)			
8 Superphosphate	26.4	25.2	21.5
9 Hyperphosphate	21.4	11.9	15.0
10 Aero-phos	20.0	7.8	14.0
L.S.D. at 5% level	3.3	1.6	1.5

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 4

TOTAL YIELDS OF ALFALFA-TIMOTHY HAY FROM FIVE CUTTINGS AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(absolute dry yield in grams, average of three cultures)

Treatment[1]		Soil Type		
		Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
1	Check (NK)	12.4	6.5	7.3
	No-lime series			
2	Superphosphate	18.5	23.1	11.9
3	Hyperphosphate	25.0	28.8	15.4
4	Aero-phos	24.5	30.0	14.5
	Lime series (1 ton)			
5	Superphosphate	22.2	23.0	20.9
6	Hyperphosphate	32.5	34.2	26.6
7	Aero-phos	30.1	25.5	21.5
	Lime series (4 tons)			
8	Superphosphate	29.5	20.0	20.2
9	Hyperphosphate	31.9	23.2	22.4
10	Aero-phos	33.6	13.9	18.5
L.S.D. at 5% level		1.8	1.5	3.9

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 5

YIELDS OF ALFALFA-TIMOTHY HAY BY CUTS AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(absolute dry yield in grams, average of three cultures)

	Treatment[1]	Soil Type														
		Greensboro Loam					Magog Stony Loam					Sheldon Sandy Loam				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	Check (NK)	1.6	3.0	0.7	2.4	4.5	1.9	0.6	0.2	1.1	2.7	0.9	2.4	1.0	0.7	2.4
	No-lime series															
2	Superphosphate	2.4	5.1	1.3	3.6	6.1	5.5	5.1	2.5	3.6	6.4	1.1	4.9	1.2	1.7	3.0
3	Hyperphosphate	3.8	7.0	3.0	4.6	6.5	7.0	6.4	3.3	4.5	7.7	1.3	5.1	1.4	2.7	5.0
4	Aero-phos	4.5	6.8	2.1	4.3	6.8	7.5	6.8	3.8	4.8	7.1	1.2	4.9	1.3	2.9	4.3
	Lime series (1 ton)															
5	Superphosphate	5.2	5.8	2.0	3.4	5.8	5.6	5.7	2.8	3.4	5.5	4.0	5.9	1.9	2.9	6.1
6	Hyperphosphate	8.0	9.0	3.1	4.1	8.4	9.0	8.4	4.3	4.7	7.7	3.3	6.9	3.4	5.3	7.7
7	Aero-phos	7.6	8.1	2.7	3.9	7.7	7.0	5.5	3.3	3.3	6.3	3.0	6.7	2.4	2.7	6.7
	Lime series (4 tons)															
8	Superphosphate	5.8	7.8	3.2	4.6	8.1	5.2	5.2	1.6	2.8	5.2	3.7	5.2	2.2	2.8	6.3
9	Hyperphosphate	6.3	8.8	3.6	4.9	8.4	6.5	5.4	2.1	3.5	5.8	2.7	5.6	2.6	3.7	7.8
10	Aero-phos	7.6	8.5	4.1	4.2	9.3	2.1	2.5	0.9	2.3	6.1	2.5	5.1	2.2	2.9	5.8

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O).
All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 6

ROOT WEIGHTS OF ALFALFA-TIMOTHY PLANTS AFTER FIVE CUTS AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(absolute dry yield in grams, average of three cultures)

Treatment[1]	Soil Type		
	Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
1 Check (NK)	16.5	6.1	10.6
No-lime series			
2 Superphosphate	19.6	15.5	18.5
3 Hyperphosphate	23.2	17.5	23.4
4 Aero-phos	22.6	19.4	21.4
Lime series (1 ton)			
5 Superphosphate	20.5	14.8	20.3
6 Hyperphosphate	26.5	17.5	25.4
7 Aero-phos	28.3	16.4	24.2
Lime series (4 tons)			
8 Superphosphate	21.9	13.7	19.3
9 Hyperphosphate	25.0	14.7	25.4
10 Aero-phos	26.6	10.2	24.5
L.S.D. at 5% level	1.6	1.2	0.9

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 7

PERCENTAGE INCREASE OR DECREASE IN GROUND COVER OVER CHECK TREATMENT OF TIMOTHY AND ALFALFA AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON DIFFERENT SOIL TYPES

(estimation made previously to fifth cutting)

	Treatment[1]	Greensboro Loam		Magog Stony Loam		Sheldon Sandy Loam	
		Timothy	Alfalfa	Timothy	Alfalfa	Timothy	Alfalfa
	No-lime series						
2	Superphosphate	2.3	3.7	2.7	14.4	1.0	4.6
3	Hyperphosphate	3.0	11.7	1.3	24.4	2.3	8.6
4	Aero-phos	0.6	13.0	- 1.0	28.0	2.0	7.0
	Lime series (1 ton)						
5	Superphosphate	4.6	7.7	1.7	15.7	1.0	10.3
6	Hyperphosphate	6.0	33.0	3.3	41.0	7.0	27.0
7	Aero-phos	4.3	30.7	4.3	17.0	5.3	19.6
	Lime series (4 tons)						
8	Superphosphate	1.0	23.3	0.7	13.0	2.3	10.3
9	Hyperphosphate	0.3	32.7	- 0.3	16.0	5.0	17.0
10	Aero-phos	0.0	37.7	- 1.0	9.4	5.6	20.6

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O).
All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 8

BOTANICAL COMPOSITION OF HERBAGE IN HAY MIXTURE AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON GREENSBORO LOAM

(estimation of ground cover in per cent, average of three cultures)

	Treatment[1]	Prior to 1st. Cut		Prior to 3rd. Cut		Prior to 5th. Cut	
		Timothy	Alfalfa	Timothy	Alfalfa	Timothy	Alfalfa
1	Check (NK)	12.0	6.3	7.6	9.3	6.0	12.3
	No-lime series						
2	Superphosphate	16.3	10.6	11.3	14.0	8.3	16.0
3	Hyperphosphate	18.0	16.6	12.6	20.0	9.0	24.0
4	Aero-phos	18.3	14.0	13.3	19.6	6.6	25.3
	Average	17.5	13.7	12.4	17.9	8.0	21.8
	Lime series (1 ton)						
5	Superphosphate	15.3	15.0	11.3	18.0	10.6	20.0
6	Hyperphosphate	20.6	25.0	12.6	35.0	12.0	45.3
7	Aero-phos	20.3	30.0	14.0	40.3	10.3	43.0
	Average	18.7	23.3	12.6	31.1	11.0	36.1
	Lime series (4 tons)						
8	Superphosphate	16.0	20.3	10.6	30.6	7.0	35.6
9	Hyperphosphate	18.3	28.6	11.0	35.6	6.3	45.0
10	Aero-phos	18.0	30.0	12.3	38.6	6.0	50.0
	Average	17.4	26.3	11.3	34.9	6.4	43.5
	L.S.D. at 5% level	8.0	26.7	5.6	35.2	6.8	43.3

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 9

BOTANICAL COMPOSITION OF HERBAGE IN HAY MIXTURE AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON MAGOG STONY LOAM

(estimation of ground cover in per cent, average of three cultures)

Treatment[1]	Prior to 1st. Cut		Prior to 3rd. Cut		Prior to 5th. Cut	
	Timothy	Alfalfa	Timothy	Alfalfa	Timothy	Alfalfa
1 Check (NK)	15.0	6.3	8.0	12.0	5.3	10.6
No-lime series						
2 Superphosphate	20.0	15.0	12.0	20.6	8.0	25.0
3 Hyperphosphate	15.6	28.6	10.3	33.6	6.6	35.0
4 Aero-phos	16.0	27.3	8.6	35.3	4.3	38.6
Average	17.2	23.6	10.3	29.8	6.3	32.9
Lime series (1 ton)						
5 Superphosphate	22.0	20.6	10.0	22.3	7.0	26.3
6 Hyperphosphate	17.3	35.6	12.6	40.6	8.6	51.6
7 Aero-phos	18.0	22.6	11.3	25.6	9.6	27.6
Average	19.1	26.3	11.3	29.5	8.4	35.2
Lime series (4 tons)						
8 Superphosphate	11.0	16.3	10.0	20.3	6.0	23.6
9 Hyperphosphate	10.0	20.0	8.0	23.0	5.0	26.6
10 Aero-phos	10.6	15.6	8.3	18.0	4.3	20.0
Average	10.5	17.3	8.8	20.4	5.1	23.4
L.S.D. at 5% level	12.7	26.1	5.3	27.7	5.7	35.1

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 10

BOTANICAL COMPOSITION OF HERBAGE IN HAY MIXTURE AS INFLUENCED BY SUPERPHOSPHATE AND ROCK PHOSPHATES WITH AND WITHOUT LIME ON SHELDON SANDY LOAM

(estimation of ground cover in per cent, average of three cultures)

	Treatment[1]	Prior to 1st. Cut		Prior to 3rd. Cut		Prior to 5th. Cut	
		Timothy	Alfalfa	Timothy	Alfalfa	Timothy	Alfalfa
1	Check (NK)	10.0	5.3	6.0	6.3	5.0	8.0
	No-lime series						
2	Superphosphate	18.0	5.3	10.0	10.3	6.0	12.6
3	Hyperphosphate	18.6	10.6	11.3	15.6	7.3	16.6
4	Aero-phos	19.3	11.6	11.3	16.0	7.0	15.0
	Average	18.6	9.2	10.9	14.0	6.8	14.7
	Lime series (1 ton)						
5	Superphosphate	20.0	10.6	7.0	12.6	6.0	18.3
6	Hyperphosphate	22.0	12.6	14.3	25.6	12.0	35.0
7	Aero-phos	25.3	12.6	11.0	24.0	10.3	27.6
	Average	22.4	12.0	10.8	20.7	9.4	27.0
	Lime series (4 tons)						
8	Superphosphate	16.0	8.6	7.0	15.6	7.3	18.3
9	Hyperphosphate	14.3	10.6	11.0	18.0	10.0	25.0
10	Aero-phos	15.3	10.6	12.3	20.6	10.6	28.6
	Average	15.2	10.0	10.1	18.1	9.3	24.0
	L.S.D. at 5% level	13.4	8.4	8.3	18.7	7.5	26.2

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O). All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

TABLE 11

CHEMICAL ANALYSIS OF ROCK PHOSPHATES (PER CENT)

Composition	Florida Aero-phos[1]	Reno Hyperphosphate[2]
Moisture and organic matter	4.64	4.93
Phosphoric acid (P_2O_5)	35.05	27.50
Iron oxide (Fe_2O_3)	0.81	0.70
Aluminum oxide (Al_2O_3)	1.05	1.25
Fluorine (F)	3.66	2.56
Eq. to Calcium Fluoride (CaF_2)	7.52	5.25

[1] Florida Aero-phos had a degree of fineness allowing 50 to 85 per cent to pass through a 200-mesh U. S. standard screen.

[2] Reno Hyperphosphate had a degree of fineness such that 90 per cent passed through a 300-mesh French standard screen.
The 300-mesh French standard screen has an aperture of 0.05 mm. comparing closely with the aperture of the 270-mesh U. S. standard screen of 0.053 mm.

TABLE 12

CHEMICAL AND PHYSICAL COMPOSITION OF SOILS

Analysis	Soil Type		
	Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
Chemical analysis			
Soil pH	5.4	6.6	5.1
Organic matter (per cent)	4.9	2.4	4.3
Exchangeable cations m.e./100 gm.			
Calcium	6.54	3.35	0.75
Magnesium	0.41	4.17	0.07
Potassium	0.42	0.11	0.08
Hydrogen	3.95	0.95	7.44
Base exchange capacity m.e./100 gm.	11.32	8.58	8.34
Adsorbed phosphorus (P) p.p.m.	46.1	3.3	3.0
Physical analysis (per cent)			
Gravel < 1 mm.	8.0	23.0	0.0
Sand 1 - .05 mm.	40.0	45.2	58.6
Silt .05 - .005 mm.	47.0	36.8	30.6
Clay > .005 mm.	12.5	18.0	10.8

TABLE 13

THE INFLUENCE OF TREATMENTS ON SOIL REACTION AS ESTIMATED AFTER THE REMOVAL OF ONE CROP OF OATS AND FIVE CUTS OF HAY

Treatment[1]	Soil Type		
	Greensboro Loam	Magog Stony Loam	Sheldon Sandy Loam
1 Check (NK)	5.52	6.81	5.20
No-lime series			
2 Superphosphate	5.63	6.78	5.32
3 Hyperphosphate	5.68	6.82	5.45
4 Aero-phos	5.70	6.84	5.40
Lime series (1 ton)			
5 Superphosphate	6.22	7.10	6.28
6 Hyperphosphate	6.27	7.18	6.48
7 Aero-phos	6.25	7.12	6.52
Lime series (4 tons)			
8 Superphosphate	7.33	8.00	7.40
9 Hyperphosphate	7.52	8.13	7.51
10 Aero-phos	7.44	8.11	7.46
Soil pH before test	5.40	6.60	5.10

[1] All treatments received N and K, at seeding time, at the following rates per acre: 200 lb. nitrate of soda (16% N) and 200 lb. of muriate of potash (50% K_2O).

All phosphates were applied on an equivalent available basis, at seeding time, at the rate of 160 lb. P_2O_5, simulating 40 lb. per acre per year.

Figure II.-The influence of phosphate carriers on the height of oats after 60 days' growth on Sheldon soil.

Left to right: Check (NK); 153, superphosphate; 154, Hyperphosphate; 155, Aerophos.

Figure III.-The influence of superphosphate with and without lime on the height of oats after 60 days' growth on Sheldon soil.

Left to right: Check (NK); 145, superphosphate, no lime; 149, superphosphate, 1 ton; 153, superphosphate, 4 tons.

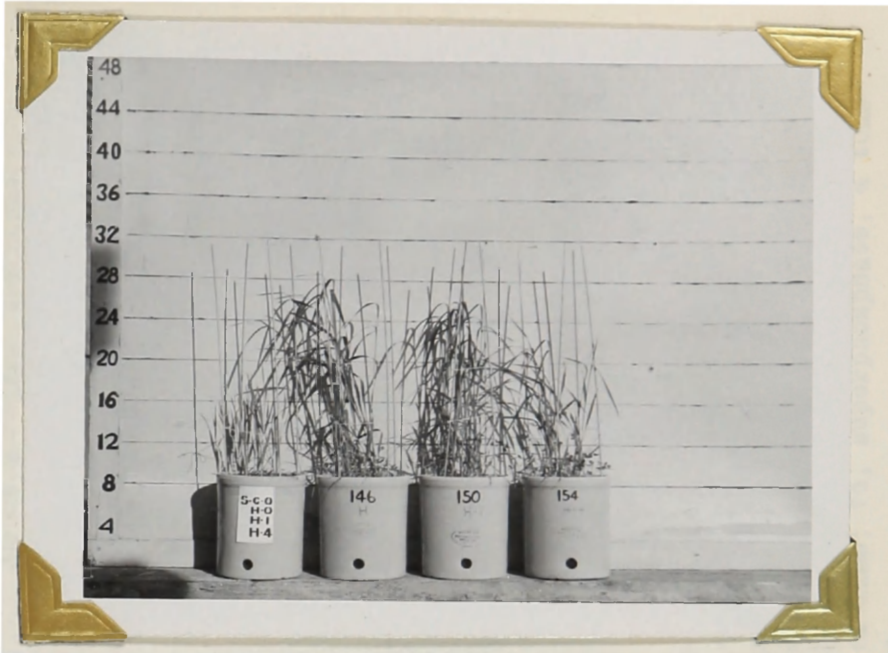

Figure IV.-The influence of Hyperphosphate with and without lime on the height of oats after 60 days' growth on Sheldon soil.

Left to right: Check (NK); 146, Hyperphosphate, no lime; 150, Hyperphosphate, 1 ton; 154, Hyperphosphate, 4 tons.

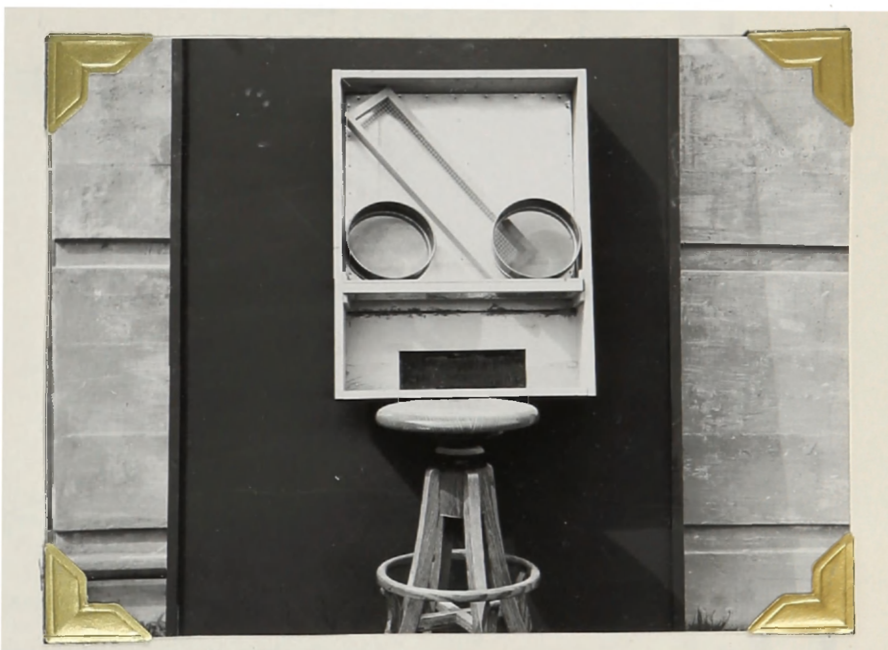

Figure V.-The tray used for washing roots. Inside view showing two circular sieves and replaceable rectangular screen for segregation.

Figure VI.-The influence of phosphate carriers with four tons of lime on the maturity of oats on Greensboro loam.

Left to right: 63, superphosphate; 64, Hyperphosphate; 65, Aero-phos.

Figure VII.-The influence of lime treatments on superphosphate on the maturity of oats on Sheldon soil.

Left to right: 67, Check (NK); 68, superphosphate, no lime; 71, superphosphate, 1 ton of lime; 74, superphosphate, 4 tons of lime.

Figure VIII.-The influence of lime treatments on Aero-phos prior to the first cut of hay on Magog soil.
Left to right: 10, Aero-phos with 4 tons of lime; 7, Aero-phos with 1 ton of lime; 4, Aero-phos without lime; 12, check (NK).

Figure IX.-The influence of lime treatments on superphosphate prior to the first cut of hay on Greensboro soil.
Left to right: 52, superphosphate with 4 tons of lime; 38, superphosphate with 1 ton of lime; 57, superphosphate without lime; 45, check (NK).

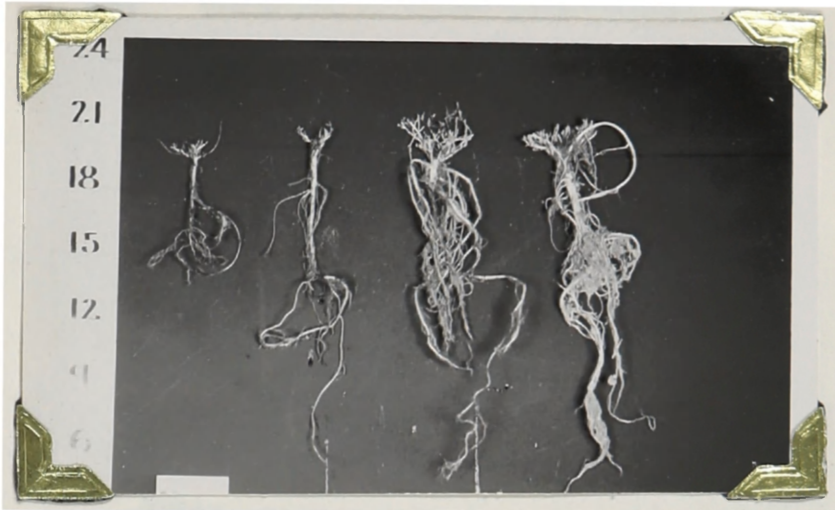

Figure X.-The root growth of alfalfa after five cuts of hay, as influenced by phosphate carriers, on Magog soil.

Left to right: Check (NK); superphosphate; Hyperphosphate; Aero-phos.

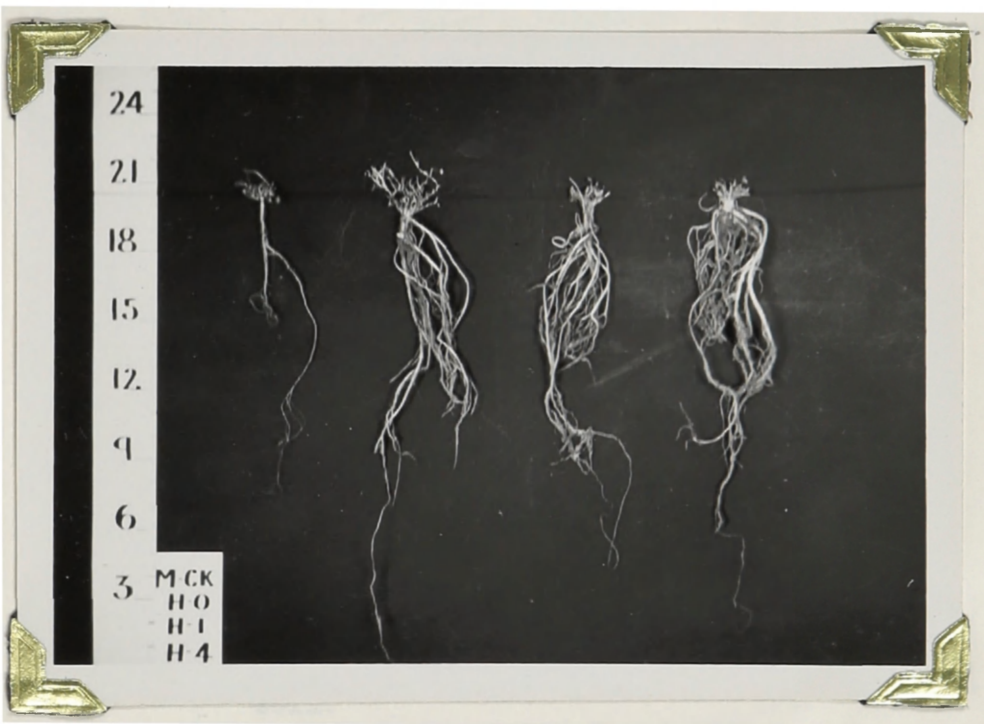

Figure XI.- The root growth of alfalfa after five cuts of hay, as influenced by lime treatments on Hyperphosphate, on Magog soil.

Left to right: Check (NK); Hyperphosphate, no lime; Hyperphosphate, 1 ton; Hyperphosphate, 4 tons.

Figure XII.-The root growth of alfalfa after five cuts of hay, as influenced by lime treatments on Aero-phos, on Magog soil.

Left to right: Check (NK); Aero-phos without lime; Aero-phos with 1 ton of lime; Aero-phos with 4 tons of lime.

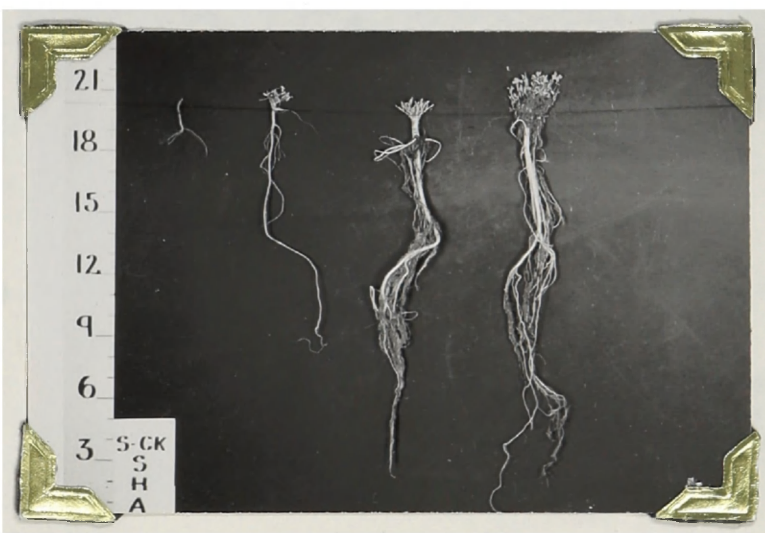

Figure XIII.-The root yields of alfalfa after five cuts of hay, as influenced by phosphate carriers on Sheldon soil.

Left to right: Check (NK); superphosphate; Hyperphosphate; Aero-phos.

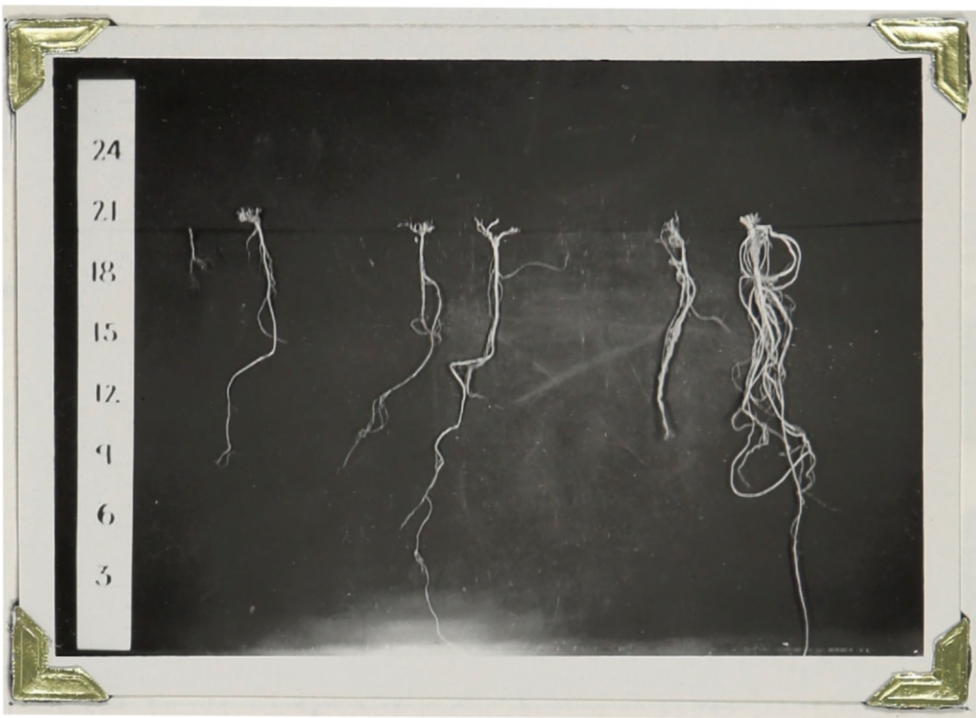

Figure XIV.-The root growth of alfalfa after five cuts of hay, as influenced by superphosphate on Greensboro, Magog and Sheldon soils.

Left to right: Check (NK) and superphosphate on Sheldon soil; check (NK) and superphosphate on Magog soil; check (NK) and superphosphate on Greensboro soil.

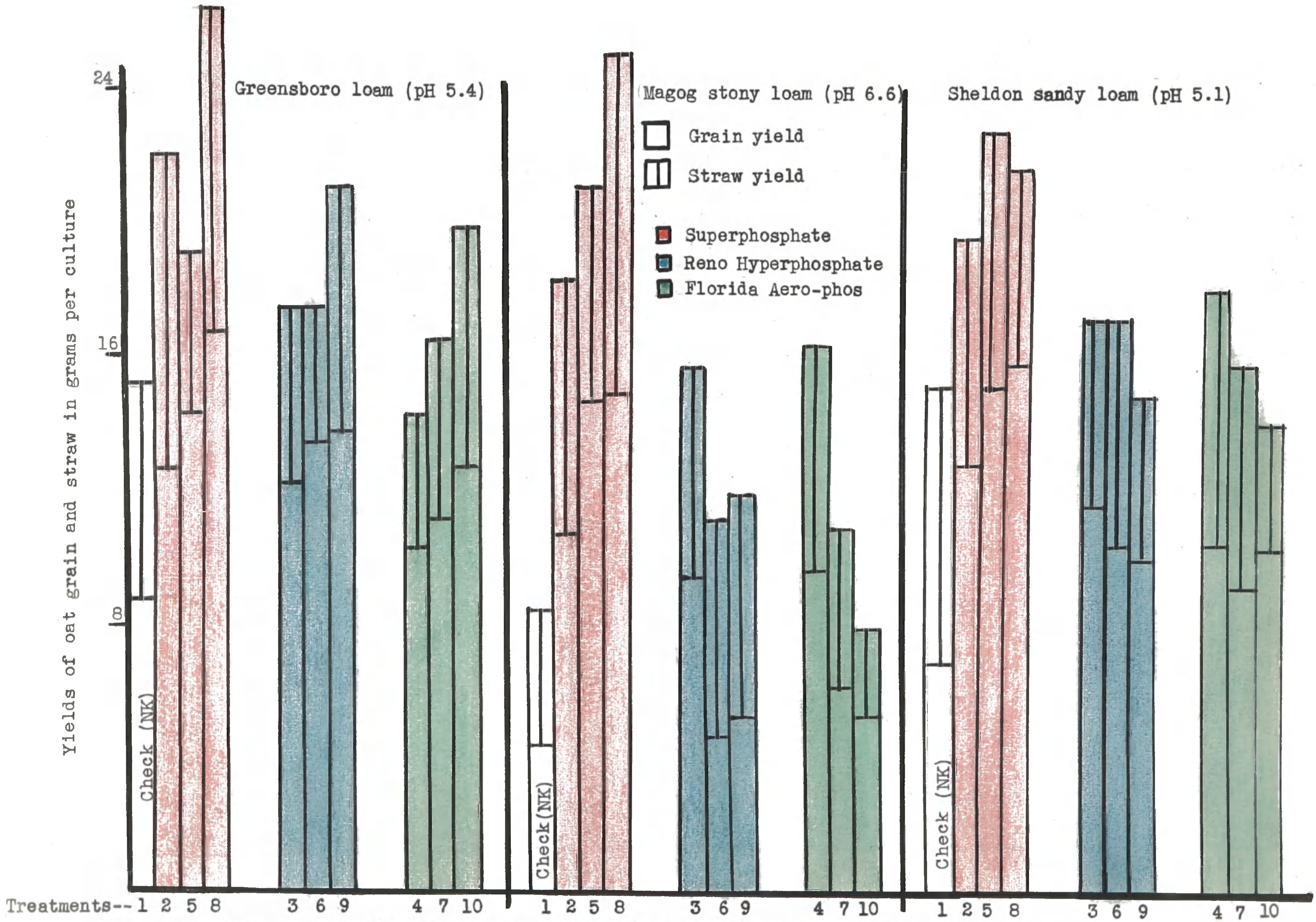

Figure XV--Yields of oat grain and straw as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

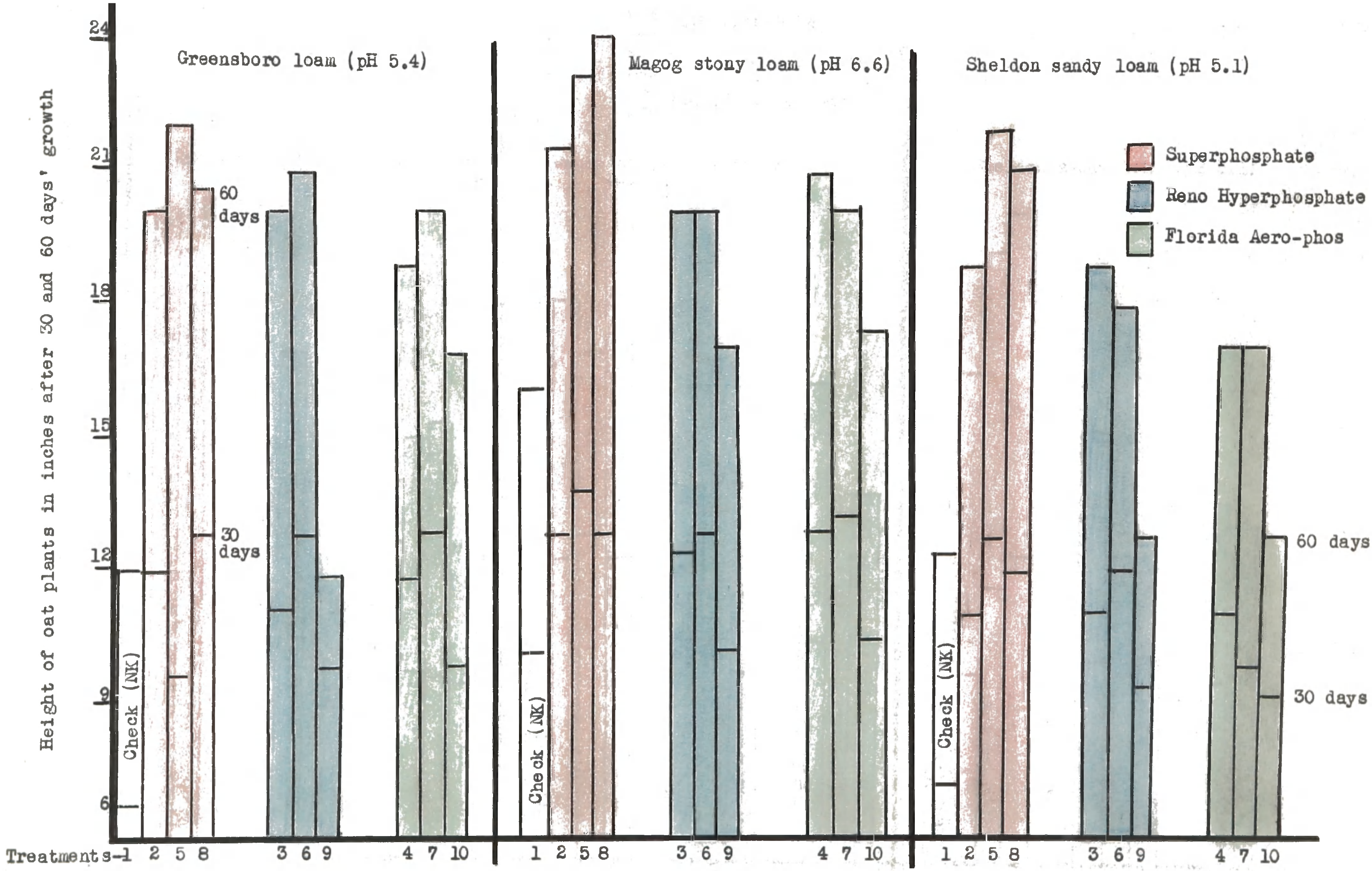

Figure XVI--The height of oat plants after 30 and 60 days' growth as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

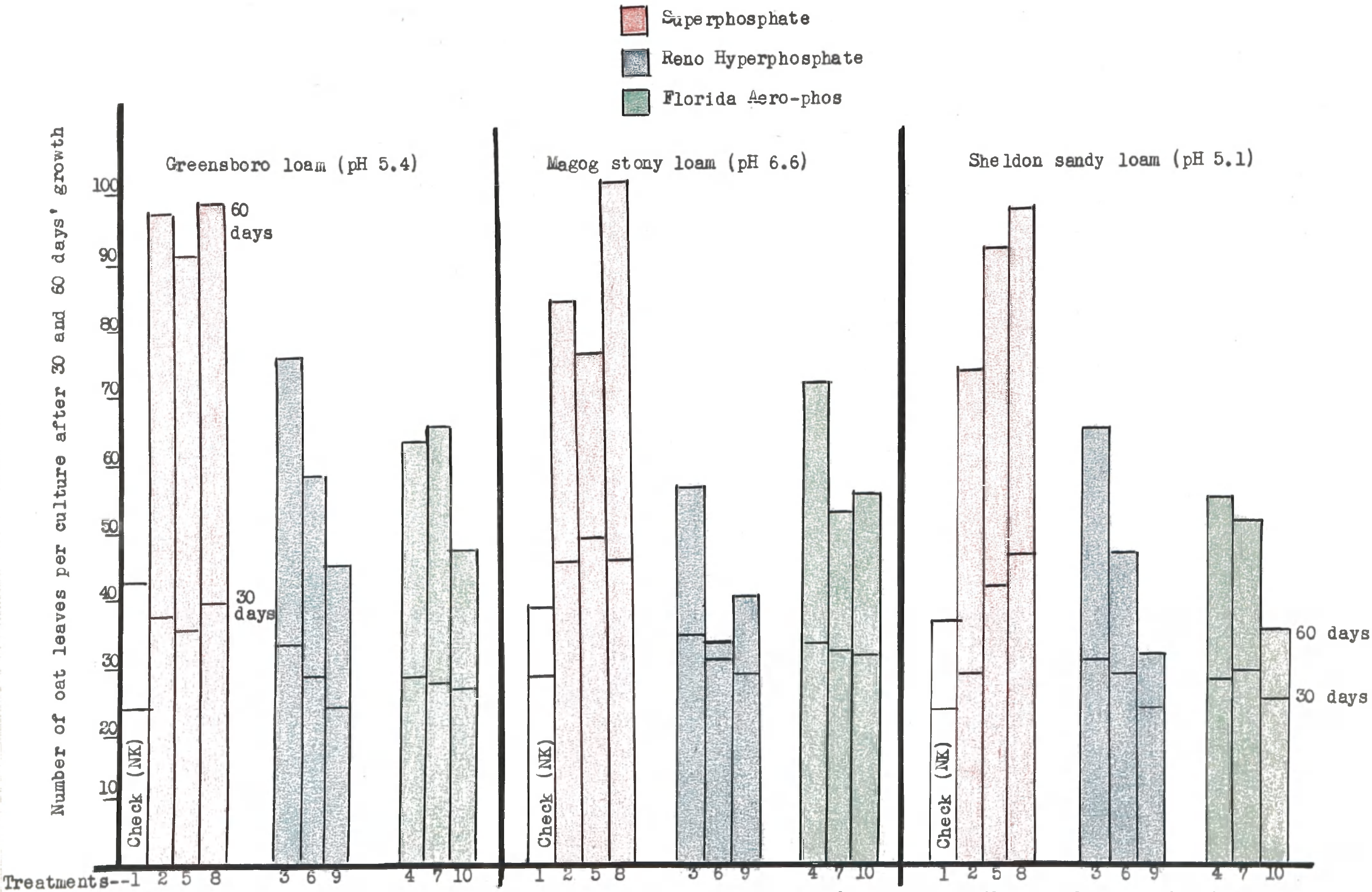

Figure XVII--The number of oat leaves after 30 and 60 days' growth as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

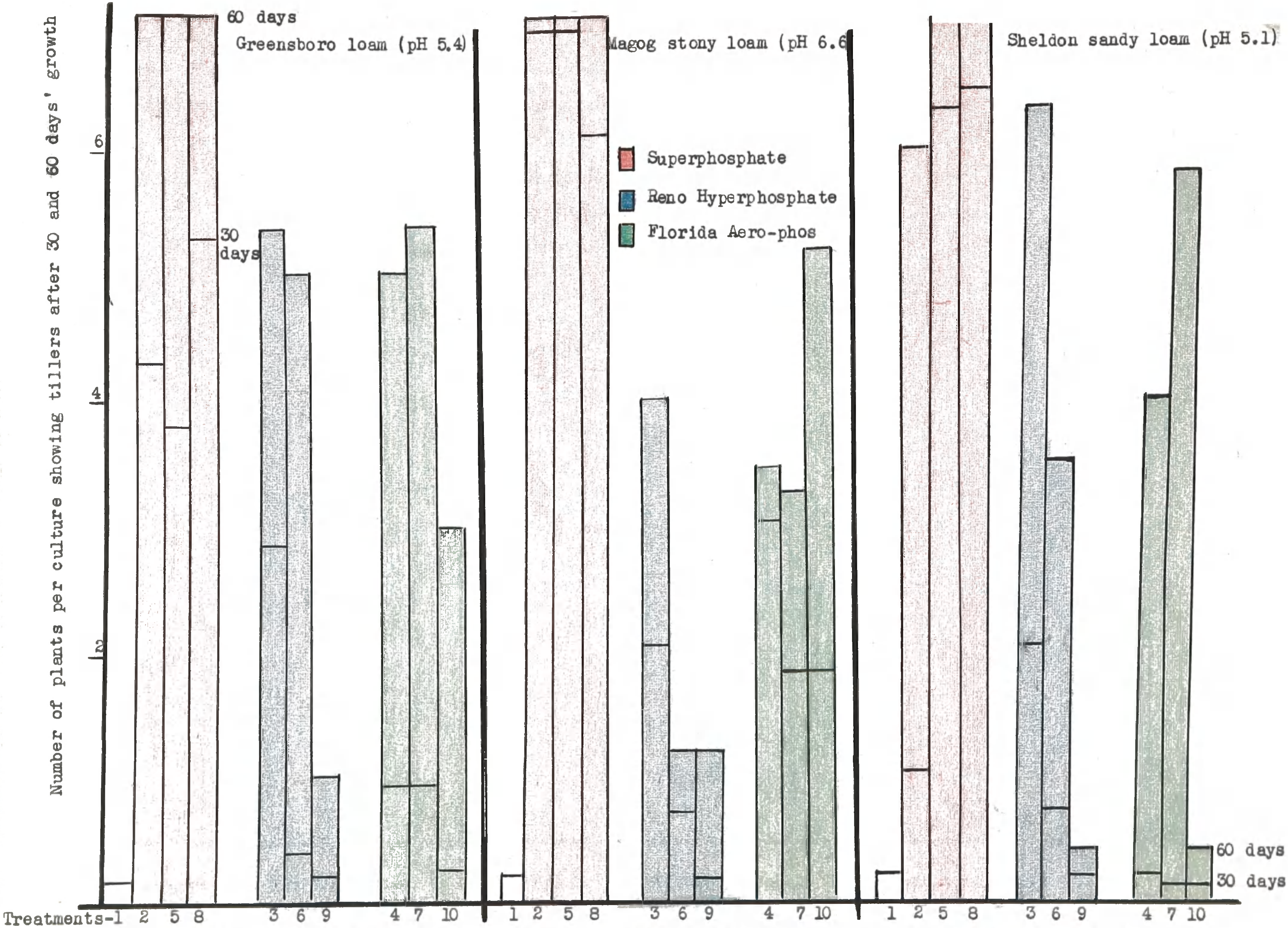

Figure XVIII--The tillering of oats after 30 and 60 days' growth as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

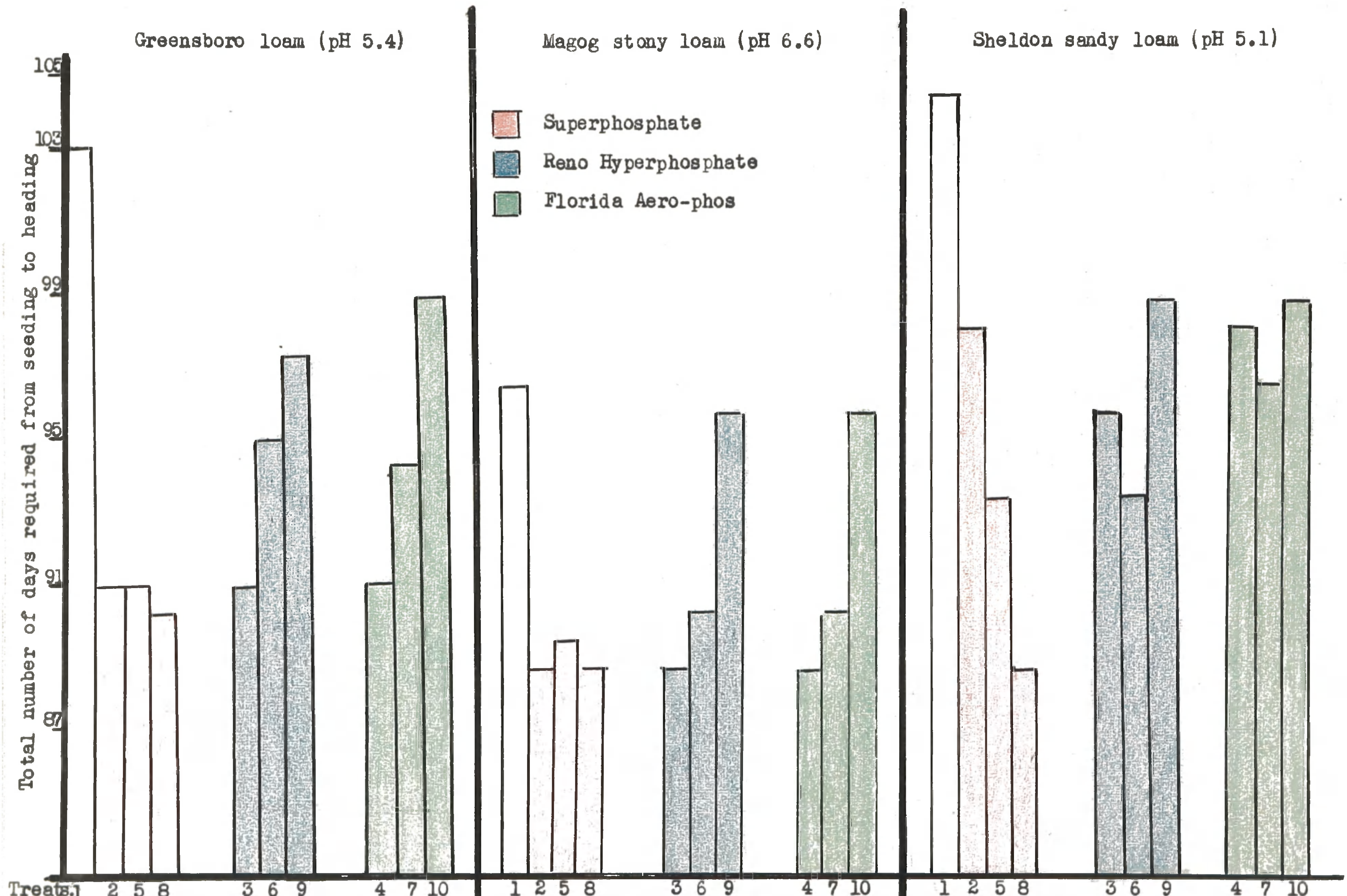

Figure XIX--The heading out of oats as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

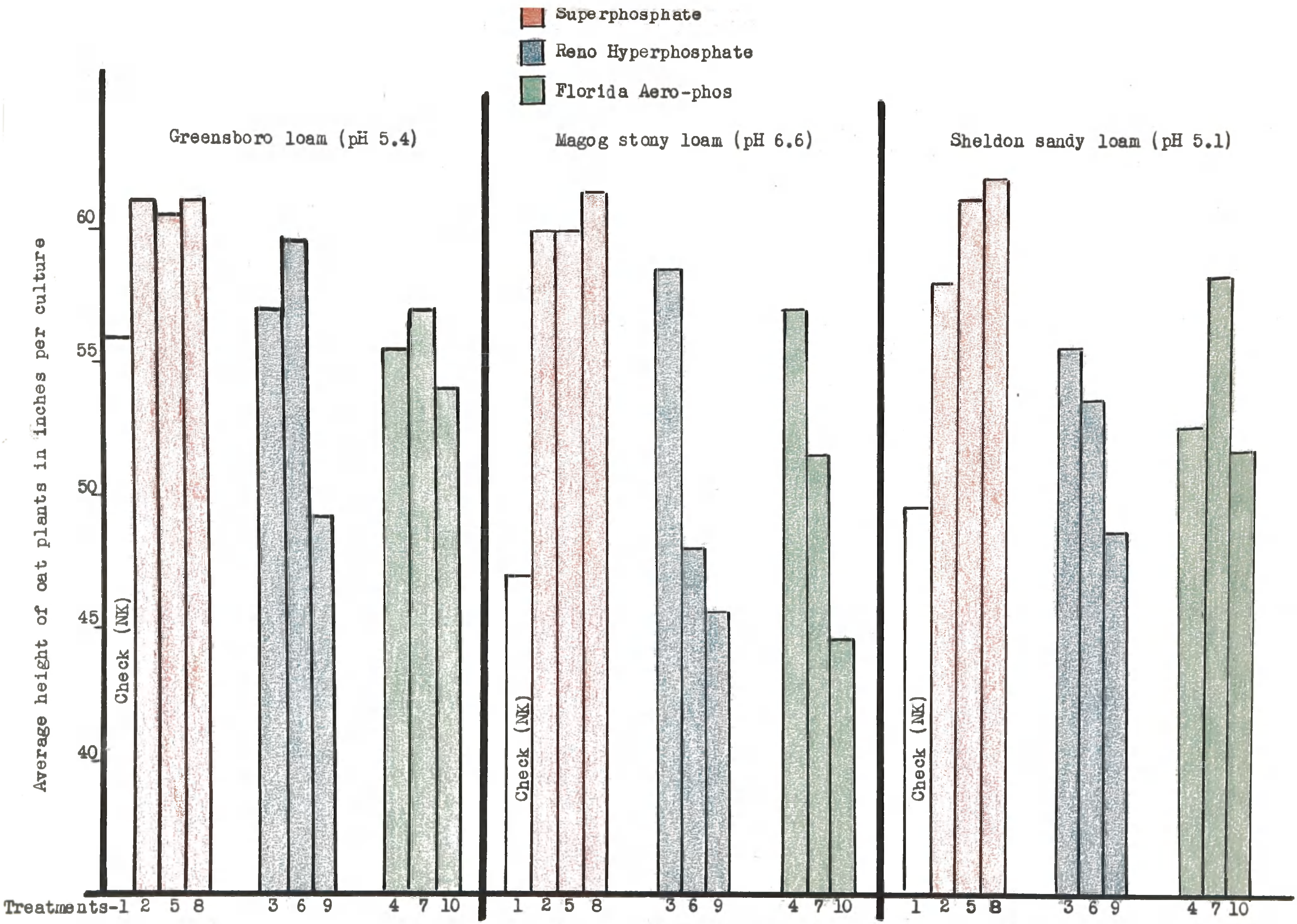

Figure XX--The height of oats at harvest time as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

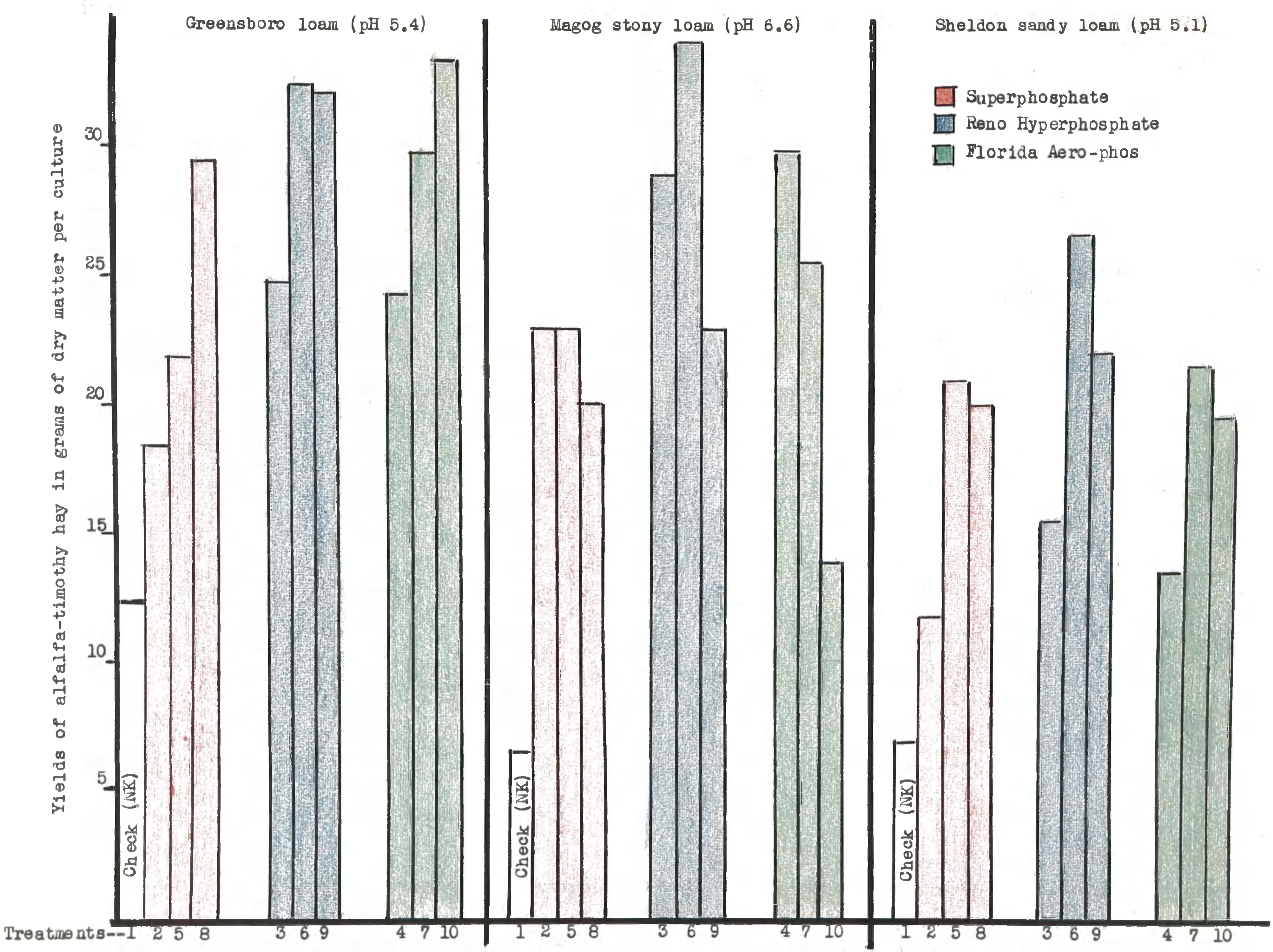

Figure XXI--Total yield of alfalfa-timothy hay from 5 cuts as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

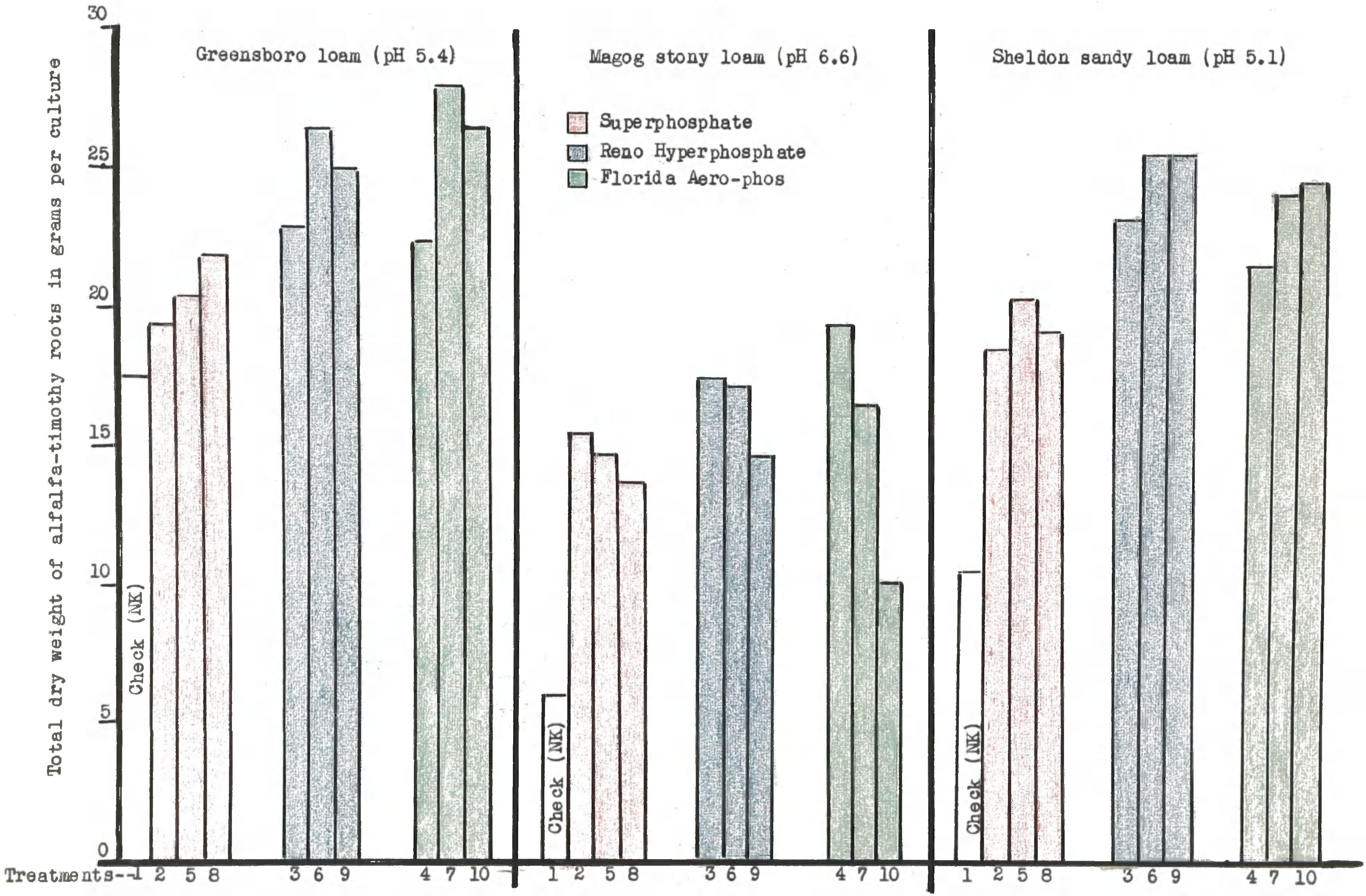

Figure XXII--Root weights of alfalfa-timothy plants after 5 cuts of hay as influenced by superphosphate and rock phosphates, with and without lime, on different soil types.

SUMMARY AND CONCLUSIONS

The data for this study were obtained from a greenhouse experiment in which two commercial forms of rock phosphate were tested against ordinary superphosphate on three soil types common to the Eastern Townships of Quebec, to determine their effects on the plant characters and yields of an oat crop, and on the yields of top and root growth of a hay mixture.

Certain plant characters of the grain crop, such as the height of plants, the number of leaves, the degree of tillering and the earliness in heading out, showed definitely more improvement with superphosphate treatment than with either of the rock phosphates, attributable to the immediate availability of the phosphorus in superphosphate.

Superphosphated soils produced yields of oats, grain and straw which, in 85 per cent of the comparisons, were significantly greater than those obtained where rock phosphates were applied.

On all soil types, Reno Hyperphosphate, in increasing the oats by 55 per cent for all grain yields, and by 22 per cent for all straw yields, proved significantly better than Florida Aero-phos.

On all soil types, superphosphate plus lime, in increasing the grain and straw yields, proved significantly better than superphosphate alone. The addition of lime to the rock phosphates caused only slight and statistically insignificant increases in the grain and straw yields from the more acid Greensboro and Sheldon soils, and a statistically significant decrease in these crops gleaned from the Magog soil, whose pH was higher.

Rock phosphated soils produced significantly heavier alfalfa-timothy hay yields, in 68 per cent of the comparisons, than those obtained where the source of phosphorus was superphosphate. The root growth of this hay mixture responded in the same manner as the top growth in 86 per cent of all yields. The superior merits of Reno Hyperphosphate were manifested in better hay and root yields which were significant in 33 and 44 per cent, respectively, of all comparisons, over those induced by Florida Aero-phos.

The value of lime at the rate of one and four tons in the production of alfalfa-timothy hay and root yields, crystallized in significantly higher yields from the more acid Greensboro and Sheldon soils, when superphosphated or rock phosphated. However, with the high rate of lime, these yields produced on superphosphated Magog soil, the least acid of the three types, lacked significance, and registered a significant decrease with rock phosphate treatments.

Further studies designed to evaluate the merits of rock phosphate-superphosphate combinations are recommended. The results of this study would seem to indicate that rock phosphates complemented with superphosphate may have a place in certain fertility programs in Quebec.

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