

"A STUDY OF THE EFFECTS OF DIFFERENT RATES OF LIMING
ON "SOIL REACTION AND GROWTH OF CERTAIN CROP PLANTS."

Major Thesis

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Subject--A study of the effects of different rates of liming on soil reaction and growth of certain crop plants.

Purpose--To determine the optimum soil reaction, as shown by the pH value, for growth of corn, wheat, barley, rye, red clover, sweet clover, alsike clover, potatoes and soybeans.

Procedure--The "Rates of Liming" experiment plats at Staunton, Virginia, will be used for this work.

INTRODUCTION

The use of lime in agriculture is one of the oldest and most universal of all farm practices. No discussion of soil fertility is complete without a reference to the uses of lime.

Results of experiments conducted, and observations made, over a period of many years have shown that the use of lime is usually followed by an increase in fertility. The amounts of lime used are dependant upon (1) type and fertility of the soil, (2) degree of acidity of the soil, and (3) the crop grown. As a rule clay soil requires heavier lime applications than does sandy soil, wet soil larger applications than does well drained soil, and that soils high in organic matter need more lime than those low in organic matter. We know that liming is especially beneficial to the growth of certain crop plants, of less benefit to the growth of others, while on still other crop plants the effect of lime is detrimental to their growth. The lime experiment, here outlined, was started in an attempt to find the best amounts of lime to apply for certain crop plants grown on a special type of soil.

THE LIME EXPERIMENT AT STAUNTON, VIRGINIA.

The data in this thesis deal with only one phase of a more extensive experiment dealing with the effect of different rates of applying lime on the response of certain crop plants. This experiment was outlined in 1922 by Prof. T. B. Hutcheson,

Supervisor of the Station, and has been conducted by E. M. Hodgson in 1922, by P. C. Manly, from 1924 to 1926, and by the writer from 1926 to the present time.

The experiment consisted of a series of 10 sub plats each, 66 ft. x 13½ ft. in dimension or 1/50 acre in area. The 9 series were cropped to three 3 year rotations as follows; corn, wheat, sweet clover; soybeans, rye, alsike clover; and potatoes, barley, and clover.

It was originally planned to apply ground limestone every third year to all of the plats (except checks). However, the growth of the crops indicated after application in 1922 and 1925, that it was not necessary to lime so frequently. It was then decided to apply the lime every sixth year; hence no lime has been applied to any of the plats since 1925. Within each series the sub plats have received the following amounts of ground limestone per acre: 600, 1200, 1800, 2400, 3000, 3600, 4200, and 4800 pounds. Each series contained two check plats, which have received no lime during the tenure of this experiment. All of the plats have received an annual application of 300 pounds of a 3-8-3 fertilizer per acre. The results of the experiment show or indicate:

(1) The utter fallacy of attempting to farm this type of soil without some form of lime. One has only to glance from the check plat to the limed plats to realize how useless it is to spend money on fertilizer until or unless the lime requirement is satisfied. The clover plats have more the appearance of demonstration than experimental plats.

(2) Up to the present time the data indicate that the

optimum application of lime is roughly 1800 pounds for the soybean-rye-alsike clover rotation, and 2400 pounds for the corn-wheat-sweet clover, and potato-barley-red clover rotations.

(3) The soil at the beginning of the experiment was very low in organic matter and the small grains and clovers have been subject to severe winter killing. There appears to be very much less of this type of injury on plats that received medium and heavy applications of lime than on the check and light-application plats. This is particularly true on the sweet clover plats, where the plants have heaved out badly quite regularly, while the plants on the limed plats have suffered only moderate injury in this respect. This may be due to; (1) an improvement in the soil texture directly due to the lime; (2) to the addition of organic matter by the turning under of better clover sods on the limed plats; and (3) to more extensive root development and to better plant anchorage where lime has been applied.

(4) There are very distinct differences in the kinds and quantities of weeds on the various limed plats. The most noticeable being the large number of Sheep Sorrel plants on the check plats. This is probably due to the fact that (1) no stable manure has been added to the experiment, (2) each rotation carries a cultivated crop every third year, and (3) to careful selection of seeds free from weed seed. It was planned to make an attempt to identify and count the weeds on the clover plats during the growing season of 1930, but this was prevented by the drought of that period.

A STUDY OF THE EFFECT OF DIFFERENT RATES OF LIMING ON SOIL REACTION AND GROWTH OF CERTAIN CROP PLANTS

Review of Literature

One of the most important papers published bearing upon this subject is one published by M. F. Morgan (1) on "Factors Affecting the Estimation of Lime Requirement from pH Values." Concerning the measurement of soil acidity Morgan states that; "The use of pH values as a measure of soil reaction has developed from a complicated laboratory technique employed in a very few experiment station research laboratories 10 years ago to a nearly universally employed routine determination. It is used not only by the investigator but by the extension specialist, farm advisor, and by an increasing number of practical growers of both fancy and staple crops. Although there are many differences in detail as to the method employed, the results obtained are comparable in their expression of the actual hydrogen-ion concentration of the soil in terms of pH.

"As yet we cannot state whether the injurious effects of soil acidity (in its broader sense) upon the growth of most economic crops is a direct function of the hydrogen-ion concentration or whether the depression of favorable biological activities in the soil, the higher concentrations of soluble aluminum and manganese, or the lower quantities of replaceable calcium or other bases may be the factor or factors which should be properly charged with adversely affecting the crop on acid soils. However

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there is a general correlation of these various soil acidity phenomena with the intensity of soil acidity as measured in terms of pH. Since its measurement is relatively simple and accurate, it will continue to be more widely employed, to the point where few progressive farmers will be ignorant of the soil reaction of any cultivated field.

"Yet the measurement of soil acidity in terms of pH makes no direct expression of the quantity of liming material which is required to change the reaction to a desired more favorable one. A measure of the temperature of a room, as, for instance, 40 degrees F., does not express directly the amount of heat required to bring the air in the room to, say 70 degrees F. Yet we can easily make such a calculation, if humidity, pressure, and insulation are also known.

"In our older methods of measurement of soil acidity the results were expressed in terms of "lime requirement"; in other words, of the number of pounds or tons of CaO or CaCO_3 required to bring an acre of surface soil to conditions of approximate neutrality. There were wide discrepancies between the figures obtained by different methods, as was clearly pointed out by Stevenson (2). Yet some of them, such as the Veitch (3) and Jones (4) methods in this country, and the Hutchinson-MacLennan (5) method in Europe, gave results which compared favorably with the amount of lime required in actual practice to neutralize the soil.

"Since the measurement of pH is more rapid and simple than

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most lime requirement methods, and gives results which much more directly express the degree of severity of the various adverse factors associated with soil acidity, it is now more widely employed than the methods which measure acidity directly in terms of "lime requirement". It would be of much added value if we could use the pH test to determine this "lime requirement" as well.

"This article is submitted as evidence that, for practical purposes, it is possible to calculate with reasonable accuracy the amount of lime or limestone required either to bring the soil to the neutral point, or to bring it to some desired less acid condition than that existing.

"In a number of cases there has appeared to be a direct correlation between lime requirement and hydrogen-ion concentration, as expressed in pH values, in comparisons of a particular soil at varying degrees of acidity. Thus Blair and Prince (6), in comparing pH with lime requirement by the Veitch method, found a close relationship when testing different plots of the same soil type, which has been variously treated. They suggested that pH measurement might be made to serve as a lime requirement method. In a later publication (7) they state: "for normal soils a determination of pH values may be of considerable assistance in arriving at the amount of lime required for general farm crops."

"Burgess (8), in comparing the effects of past fertilizer treatments in field plots at the Rhode Island Experiment Station, found a fair correlation between acidity as indicated by pH values and the Jones lime requirement.

"Johnson (9), working with soil of various types, found "no relationship... between the Veitch lime requirement and pH." The Truog (10) method of estimating lime requirement gave a slight correlation. With soil of similar type there appeared to be a relationship between the apparent quantity and strength of soil acids. Since clay and organic matter act as buffers in keeping the hydrogen-ion concentration down, soils of different types with respect to these buffer substances would be expected to give different results."

"Parker and Bryan (11), in comparing the pH, the Truog lime requirement, and the hydrolysis of ethyl acetate, found a fairly good correlation in the 42 soils under comparison.

"Jensen (12), in an investigation of the acidity of 115 Danish fields, concluded that a single pH determination is inadequate for computing the lime requirement.

"Carleton (13), in a comparison of pH value with the Jones lime requirement of Quebec soils, found that soils of various types exhibited no correlation, whereas soil of the same textual character gave indications of correlation.

"Saint (14), in a comparison between pH, the thiocyanate color test for estimating acidity developed by Comber (15), and the lime requirement by the Hutchinson-MacLennan method, found only a rough correlation for the soils examined."

In his summary Morgan states; "The increasing use of pH tests in soil studies presents a growing need for the practical utilization of these tests as a guide to liming practice.

"Results of previous investigation have, in general, indicated a correlation between pH and lime requirement, particularly on soils of the same type. The factors which affect this correlation have not been studied in detail.

"In a study of the reaction and lime requirements of several hundred tobacco fields in the Connecticut Valley, a tabulation of the data showed an excellent correlation between pH and lime requirement for soils of approximately the same texture and organic content. An increase in organic matter and a heavier texture both produce a larger value of the "lime absorption factor," which represented the amount of lime required to decrease the acidity 1 pH. An approximate table of factors was calculated which appeared to be of general application to this group of soils.

"More detailed studies were conducted on other soils which have been under investigation in the greenhouses of the Connecticut Agricultural Experiment Station, and which represent all the important soil types of the state. A study of the rate of change in reaction produced by amounts of CaCO₃ corresponding to 1/2, 1, 1 1/2, and 2 times the Jones lime requirement on 14 of these soils revealed the fact that there is a constant difference in relative effectiveness of lime in these proportions, and that a constant factor is in operation on each individual soil which determines the amount of lime required to produce a given change in pH toward the neutral point. An inspection of these data as related to the physical characteristics of these soils, suggests that the value of this factor can be approximately determined from a

study of the mechanical analysis, organic content, and moisture constants of the soil.

"A group of 56 soils were thus investigated. A most striking correlation between moisture equivalent and the "CaCO₃ absorption factor" was revealed. Since the moisture equivalent is in effect a measure of the summation of the effect of differences in texture and organic content upon the absorptive properties of the soil. this result is not difficult to explain. It lends weight to the view that the lime requirement of the soil is a logarithmic function of the actual H-ion concentration and a direct function of the specific absorptive characteristics of the soil.

"Since the amount of CaCO₃ required to produce a change of 1 pH in reaction toward 7 pH can be expressed by multiplying the moisture equivalent by the factor 0.119, and since the moisture equivalents of soils of different textures and organic contents are relatively constant, a table of CaCO₃ absorption factors for the various textural classes at varying organic contents has been prepared. It has proved to be of good general application on a group of 100 random samples of soils from all parts of Connecticut, and is believed by the writer to be suitable for the estimation of lime requirement from pH values for most normal soils in the humid region of eastern United States."

Further comments on the measurement of acidity may be found in; "The A B C of Hydrogen Ion Control" published by the La Motte Chemical Products Co., Baltimore, Md. (16)

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"During the past few years control of acidity and alkalinity, by means of Hydrogen Ion Measurements, has come into very extensive use in all types of Research and Industrial work, and the number of practical applications in the various fields is steadily increasing. The Colorimetric Method is being widely adopted because it is far more simple, rapid and economical than any other method.

"The reaction of the soil is one of the few important properties which can be quickly and accurately measured. Whether a soil is acid, neutral or alkaline, and the degree of acidity or alkalinity, has long been known to be one of the controlling factors in plant growth, but only since pH measurements have been applied to soils has it been possible to express this relationship in precise terms.

"The soil is a marvelously complicated medium or mechanism in which innumerable physical and chemical reactions take place and which under the eye of the high power microscope appears veritably alive with bacteria, fungi and other organisms. Since physical conditions, chemical changes and life of all kinds are known to be greatly affected by the reaction of the surrounding medium, it is self apparent that the reaction of a soil must have a profound influence upon the plants that grow in it. We are interested in soils primarily because they furnish a home and supply sustenance for economic and ornamental plants. The relation of plant and soil is a most intimate one.

"Ideal conditions for plant growth are attained only when the physical condition of the soil is properly regulated, when

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bacterial activity of the right kind takes place, By a proper regulation of physical condition it is meant that the colloidal matter of soils is kept largely in a flocculated condition, in order that heavy soils may be kept open and porous, thus allowing a ready entrance of air and water, and the removal of an excess of water by under-drainage. The close connection between reaction and physical condition of colloids is well known and has direct application to soils, for soils consist to a considerable extent of colloidal material. It is in fact the colloidal material that exercises a controlling influence on the character of most soils.

"The most favorable physical condition of a soil is usually obtained when the reaction of the soil lies in the range of pH 6.0 to 8.0. In arid or semi-arid regions, alkalis may accumulate until the soil has a pH as high as 9.8 or 10.0. This is due to the presence of sodium carbonate. Alkalinity indicated by a pH value above 8.0 adversely affects the growth of many plants.

"High alkalinity causes a deflocculation of the soil, that is, the soil granules break down and the particles run together forming a hard compact soil with too little pore space. On the other hand if the soil is more acid than pH 6.0, it also tends to deflocculate, although not anywhere near to the extent that it does under too alkaline conditions, It is true, however, that some plants grow best in a soil which has a pH value below 6.0. Cultivated soils rarely show an acidity stronger than pH 4.0.

"Because of the great variation in the reaction of soils and because of the profound influence of soil reaction on soil fertility, it is highly desirable that all soils be tested and their reaction determined in order that needed corrections may

be made. The pH value, either directly or indirectly, indicates whether or not the most common agricultural crops and many other plants can make normal growth, regardless of other favorable conditions.

"The soil, if acid beyond the best range of the plant to be grown, must be limed in sufficient quantity to produce favorable pH. This does not mean liming to neutrality if the crop does not require a neutral reaction. In general the use of lime on acid clay soils in time greatly improves their physical condition, thus facilitating their workability and aeration. On acid sandy soils, the use of lime helps to bind the particles together and thus decrease the too great looseness.

"The availability of the phosphorus, an essential element for all plant growth, is greatly influenced by the soil reaction. If the soil becomes too acid, the phosphorus often decreases in availability to a point at which the plant suffers for the need of this element. In fact most all of the essential elements which the plant obtains from the soil are kept in a more available condition when the acidity is not allowed to become much greater than pH 6.0.

"The nitrogen fixing bacteria that live in the nodules on the roots of our most valuable legumes, cannot live long or function properly in a soil that has become strongly acid. Under these conditions the nitrogen supply of the soil cannot be replenished except a great cost through the use of nitrogen fertilizers. The bacteria involved in changing various forms of nitrogen to the nitrate form, which is the form most usable by plants, work best at a pH of 6.0 to 8.0

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SEASONAL VARIATIONS IN SOIL REACTION
AS SHOWN BY THE pH VALUES.

In order to study the relation of soil reaction to crop response, it became necessary to decide upon a definite time of the season in which the pH should be determined. Since information on the effect of the crop and season on the soil reaction is very meagre, it seemed advisable to make a study of the pH values of the different plots throughout an entire year, in order to determine whether the tests should be made at a certain time or whether the tests might be made at any time during the season.

Methods and Materials Used.

Composite soil samples from each of the sub-plats were taken the last week in each month, beginning March 1930 and ending February 1931. The samples were taken to a depth of four inches by means of a soil auger. Two borings were made on each sub-plot.

The pH determinations were made with a "Morgan Soil Testing Set", manufactured by the La Motte Chemical Products Co., Baltimore, Md.

Experience with this testing set leads the writer to believe that it is not entirely accurate. Thus, repeated determinations on the same soil sample did not always yield identical pH values. Furthermore, it was often difficult to match, satisfactorily, the shade of color developed by the soil with the standard color charts provided with the testing equipment. The moisture content of the soil, the rapidity with which the indicator dye penetrated the

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soil sample, the intensity of light and perhaps other factors, are also believed to have some effect on the color developed. These possible sources of error however are believed to have been reduced to a minimum in the investigation reported here, particularly because average pH values are used in many cases rather than individual readings; also because the investigation is based on a total of 1080 individual determinations.

Results

The results of the tests made on the various sub-plats throughout the year on the corn, wheat, and sweet clover rotation are given in Tables 1 to 3 inclusive, those for the soybean, rye, and alsike clover rotation in Tables 4, 5, and 6, and for potatoes, barley, and red clover in Tables 7, 8, and 9. These detailed data are summarized for each crop in Table 10, and for all crops combined in Table 11. These tables show that the reaction of the soil on the various plats was relatively consistent throughout the year. Minor fluctuations occurred, but they showed no consistent trend. There was a noticeable increase in pH where the larger amounts of lime were used. It should be born in mind that the crops were a failure in 1930 and there was comparatively little plant growth on the plats.

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Table No. 1. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop: Corn Rotation: Corn, Wheat, Clover(Sweet).

Month of Determination	Pounds of Limestone Applied per Acre.									
	0	600	1200	1800	2400	3000	3600	4200	4800	
March	5.0	5.5	5.6	5.8	6.4	6.6	6.8	6.8	7.0	
April	5.0	5.2	5.5	5.8	6.2	6.6	6.6	6.8	6.8	
May	5.3	6.0	6.4	6.5	6.6	6.7	6.8	7.0	7.0	
June	5.4	5.8	6.4	6.6	6.4	6.6	6.6	6.4	6.4	
July	4.9	5.4	5.6	6.0	6.2	6.4	6.6	6.8	7.0	
August	4.7	5.6	5.7	5.8	6.0	6.2	6.4	6.6	6.8	
September	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	
October	4.8	5.2	5.4	5.6	6.4	6.6	6.6	6.8	6.8	
November	5.2	5.4	5.6	5.8	6.2	6.6	6.6	6.6	6.6	
December	5.2	5.4	5.6	5.8	6.0	6.2	6.2	6.6	6.8	
January	5.0	5.4	5.6	5.8	6.2	6.6	6.6	6.7	6.8	
February	5.0	5.2	5.6	5.8	6.0	6.2	6.4	6.6	6.8	

Table No. 2. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop:Wheat Rotation: Corn, Wheat, Clover(Sweet).

Month of

Determination.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.0	5.2	5.4	5.6	6.0	6.0	6.2	6.4	6.6
April	4.9	5.2	5.2	5.4	6.0	6.2	6.2	6.4	6.6
May	5.2	5.6	6.2	6.4	6.4	6.6	6.6	6.8	7.0
June	5.2	5.6	6.0	6.4	6.4	6.6	6.6	6.8	7.0
July	4.9	5.4	6.0	6.6	6.6	6.8	6.8	6.8	7.0
August	5.0	5.6	5.8	6.0	6.2	6.2	6.6	6.6	6.8
September	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8
October	4.9	5.2	5.4	5.6	6.0	6.4	6.8	6.8	7.0
November	5.0	5.4	5.6	5.8	6.2	6.6	6.6	6.6	6.6
December	4.9	5.2	5.4	5.6	5.8	6.0	6.2	6.6	6.8
January	5.2	5.4	5.5	5.6	6.0	6.4	6.4	6.5	6.6
February	5.0	5.2	5.6	5.8	6.0	6.2	6.4	6.6	6.8

Table No. 3. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop: Sweet Clover Rotation: Corn, Wheat, Clover(Sweet).

Month of Determination.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.2	5.2	5.4	5.5	6.2	6.4	6.6	6.6	6.8
April	5.1	5.2	5.5	5.6	6.2	6.4	6.4	6.8	7.0
May	5.0	5.3	6.0	6.0	6.4	6.4	6.6	6.8	7.0
June	5.0	5.4	5.7	6.2	6.3	6.6	6.8	6.8	7.0
July	4.9	5.8	5.6	5.8	6.4	6.6	6.8	7.0	7.0
August	5.0	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0
September	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8
October	4.9	5.4	5.6	5.6	6.2	6.6	6.6	6.7	6.8
November	5.3	5.4	5.6	5.8	6.2	6.4	6.6	6.7	6.8
December	5.2	5.4	5.6	5.8	6.0	6.4	6.4	6.6	6.8
January	4.9	5.2	5.6	5.8	6.0	6.4	6.6	6.8	7.0
February	5.1	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8

Table No. 4. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop:Soybeans. Rotation:Soybeans, Rye, Alsike Clover.

Month of

Determinations. Pounds of Limestone Applied per Acre.

	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.2	5.4	6.0	6.3	6.4	6.6	6.6	6.8	6.8
April	5.3	5.3	6.1	6.2	6.4	6.5	6.7	6.8	7.0
May	5.3	5.4	6.2	6.3	6.6	6.6	6.8	6.9	7.0
June	5.3	5.4	6.0	6.1	6.2	6.2	6.4	6.4	6.6
July	5.1	5.4	5.6	5.8	5.8	6.4	6.4	6.6	6.6
August	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.8	6.8
September	5.0	5.4	5.5	5.6	5.7	6.0	6.4	6.6	6.6
October	4.9	5.2	5.3	5.4	5.6	5.6	5.8	6.2	6.2
November	4.9	5.0	5.3	5.4	6.1	6.0	6.2	6.3	6.4
December	4.9	5.2	5.4	5.6	6.2	6.4	6.2	6.4	6.6
January	4.9	5.2	5.4	5.4	6.0	6.2	6.2	6.3	6.4
February	5.0	5.4	5.5	5.6	6.0	6.2	6.2	6.4	6.6

Table No. 5. The pH determinations made each month
 over a twelve month period beginning March 1930.

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1930 Crop: Rye Rotation: Soybeans, Rye, Alsike Clover.

Month of

Determination.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.4	5.4	5.6	5.8	6.2	6.4	6.6	6.8	6.8
April	5.4	5.6	5.6	5.8	6.0	6.2	6.4	6.8	6.8
May	5.4	5.6	5.8	6.0	6.3	6.5	6.6	6.8	7.0
June	5.2	5.4	5.6	6.0	6.4	6.6	6.8	6.8	6.8
July	5.0	5.4	5.6	5.8	6.4	6.6	6.6	6.8	7.0
August	5.0	5.6	5.5	5.8	6.0	6.2	6.4	6.8	6.8
September	5.0	5.6	5.8	6.0	6.0	6.2	6.6	6.8	7.0
October	5.1	5.4	5.2	5.4	6.0	6.4	6.4	6.6	6.6
November	5.0	5.4	5.6	5.8	6.2	6.4	6.6	6.6	6.8
December	5.1	5.2	5.4	5.6	6.0	6.2	6.4	6.4	6.8
January	5.0	5.4	5.5	5.6	6.0	6.2	6.4	6.5	6.6
February	4.9	5.4	5.5	5.6	6.0	6.2	6.4	6.6	6.8

Table No. 6. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop: Alsike Rotation; Soybeans, Rye, Alsike Clover.

Month of

Determination.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.0	5.2	5.6	6.0	6.4	6.4	6.6	6.8	6.8
April	5.1	5.4	5.6	5.8	6.2	6.4	6.4	6.6	6.8
May	5.2	5.4	5.6	5.7	6.2	6.4	6.6	6.6	6.8
June	5.0	5.2	6.0	6.2	6.2	6.4	6.4	6.6	6.8
July	4.9	5.6	6.2	6.4	6.4	6.6	6.8	7.0	7.0
August	4.8	5.6	5.8	6.0	6.2	6.4	6.8	7.0	7.0
September	5.0	5.5	5.8	6.0	6.2	6.6	6.6	7.0	7.0
October	5.0	5.2	5.3	5.4	6.0	6.2	6.4	6.6	6.6
November	5.1	5.4	5.6	5.8	6.2	6.6	6.6	6.6	6.8
December	4.9	5.4	5.6	5.8	6.2	6.4	6.6	6.6	6.8
January	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8
February	5.0	5.6	5.8	6.0	6.0	6.4	6.6	6.6	6.8

Table No. 7. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop:Potatoes Rotation:Potatoes, Barley, Red Clover.

Month of

Determination.	Pounds of Limestone Applied per Acre.									
	0	600	1200	1800	2400	3000	3600	4200	4800	
March	5.0	5.2	5.4	5.4	5.6	6.0	6.2	6.4	6.4	
April	5.1	5.4	5.4	5.6	6.0	6.2	6.2	6.5	6.6	
May	5.1	5.6	5.8	6.0	6.2	6.2	6.4	6.8	6.8	
June	5.2	5.6	5.6	6.0	6.0	6.2	6.4	6.8	7.0	
July	5.3	5.4	5.6	6.0	6.4	6.6	6.6	6.8	7.0	
August	4.9	5.6	5.7	5.8	6.0	6.2	6.2	6.8	7.0	
September	4.9	5.4	5.5	5.6	6.5	6.6	6.6	7.0	7.0	
October	4.8	5.2	5.3	5.4	5.8	6.0	6.2	6.0	6.2	
November	4.9	5.4	5.5	5.6	5.8	6.0	6.2	6.3	6.4	
December	4.9	5.2	5.4	5.6	6.0	6.4	6.6	6.6	6.8	
January	4.9	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.4	
February	5.0	5.4	5.5	5.6	5.0	6.2	6.2	6.3	6.4	

Table No. 8. The pH determinations made each month over a twelve month period beginning March 1930.

1930 Crop: Barley Rotation: Potatoes, Barley, Red Clover.

Month of

Determination.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.1	5.4	5.6	5.6	5.8	6.2	6.2	6.6	6.8
April	5.1	5.4	5.4	5.6	5.6	6.0	6.2	6.8	6.8
May	5.1	5.2	5.4	6.0	6.2	6.4	6.5	6.6	6.8
June	5.2	5.4	5.4	5.6	6.0	6.2	6.4	6.4	6.8
July	5.0	5.4	5.8	6.6	6.6	6.6	6.8	6.8	7.0
August	5.0	5.6	5.8	6.2	6.4	6.6	6.6	6.8	7.0
September	5.1	5.4	5.8	6.0	6.4	6.8	6.8	6.8	7.0
October	4.9	5.2	5.4	5.8	6.0	6.4	6.6	6.8	7.0
November	5.0	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8
December	4.9	5.4	5.6	6.0	6.2	6.4	6.4	6.8	7.0
January	4.9	5.4	5.4	5.6	6.0	6.2	6.4	6.8	7.0
February	5.1	5.6	5.8	6.0	6.2	6.4	6.6	6.7	6.8

Table No. 9. The pH determinations made each month
over a twelve month period beginning March 1930.

1930 Crop: Red Clover Rotation: Potatoes, Barley, Red Clover.

Month of

Determination. Pounds of Limestone Applied per Acre.

	0	600	1200	1800	2400	3000	3600	4200	4800
March	5.2	5.6	5.6	5.8	5.8	6.4	6.6	6.8	6.8
April	5.2	5.4	5.6	5.6	5.6	6.2	6.6	6.8	7.0
May	5.2	5.4	5.6	6.0	6.5	6.6	6.6	6.8	7.0
June	5.2	5.4	5.4	6.0	6.4	6.5	6.6	6.8	6.8
July	4.9	5.6	5.8	6.0	6.4	6.6	6.8	6.8	7.0
August	5.1	5.8	5.8	6.0	6.2	6.2	6.4	6.8	7.0
September	5.0	5.2	5.6	5.8	6.2	6.4	6.6	6.8	6.8
October	5.0	5.2	5.4	5.6	6.2	6.4	6.6	6.6	6.8
November	5.0	5.4	5.8	6.0	6.2	6.4	6.6	6.8	7.0
December	5.1	5.4	5.6	5.8	6.0	6.4	6.6	6.8	7.0
January	4.9	5.0	5.2	5.4	6.2	6.4	6.6	6.6	6.8
February	5.0	5.4	5.6	5.6	6.0	6.0	6.2	6.5	6.6

Table No. 10. The average of the pH determinations of the ten crop plats each month throughout the twelve month period.

Month of
Determination. Average pH of the ten crop plats.

	Corn	Wheat	S.clover-	Soybeans	Rye	A.clover-	Potatoes	Barley	Relover
Mar.	6.1	5.8	5.9	6.2	6.1	6.1	5.7	5.9	6.1
Apr.	6.1	5.8	6.0	6.3	6.1	6.0	5.9	5.9	6.0
May	6.5	6.4	6.2	6.3	6.2	6.1	6.1	6.0	6.2
June	6.3	6.3	6.2	6.1	6.2	6.1	6.1	5.9	6.1
July	6.1	6.3	6.2	6.0	6.1	6.3	6.2	6.3	6.2
Aug.	5.9	6.1	6.2	6.0	6.0	6.2	6.0	6.2	6.1
Sept.	5.9	5.9	6.0	5.9	6.1	6.2	6.1	6.3	6.1
Oct.	6.0	6.0	6.0	5.6	5.9	5.9	5.7	6.0	6.0
Nov.	6.1	6.0	6.1	5.7	6.0	6.1	5.8	6.0	6.1
Dec.	6.1	5.8	6.1	5.5	5.9	6.0	5.9	6.1	6.1
Jan.	6.0	5.9	6.0	5.8	5.9	6.0	5.8	6.0	5.9
Feb.	6.1	5.9	6.1	5.9	5.9	6.1	5.8	6.1	5.9

Table No. 11. The average of the pH determinations of all ninety sub plats each month for the twelve month period.

Month of Determination.	Average pH of all ninety plats.
March	6.0
April	6.0
May	6.2
June	6.1
July	6.1
August	6.1
September	6.1
October	5.9
November	6.0
December	6.0
January	5.9
February	6.0

THE CHANGES UNDERGONE IN SOIL REACTION OVER A TWO YEAR PERIOD AS SHOWN BY THE pH DETERMINATIONS MADE IN 1928 AND IN 1930-31.

The tendency in liming practices is towards more frequent light applications of lime rather than heavy applications made at long intervals. The amount of lime applied and the frequency of applications is dependant upon the degree of acidity of the soil and the crop to be grown. In the Staunton Experiment lime was applied every third year and then changed to every sixth year, In the belief that a knowledge of the pH changes which take place from year to year have a bearing on how frequently the lime applications should be made, the determinations made in 1930-31 are compared with a set of determinations made in 1928. Only one set of pH determinations was made in 1928. Table No. 12 shows the average of the twelve pH determinations for each crop plat made in 1930-31. These average determinations are used to compare with those made in 1928.

RESULTS

Table No. 13 and Figs. 1, 2, and 3, show a comparison of the 1928 and 1930-31 determinations. These tables show that with the exception of the red clover plats all of the plats have become more acid in 1930-31. The determinations made for the red clover plats are out of line with the other determinations made in that year, and in view of the fact that the changes on the rest of the plats are consistant, it is probably safe to assume that an error was made in the 1928 red clover determinations.

Table No. 14, gives the average of the 36 determinations for each of the three rotations used, while Fig. 4, compares these determinations with those made for the same rotations in 1928. These show that the changes which took place were consistent and that the soil of all the plats was more acid in 1930-31 than in 1928.

Table No. 12. The average of the twelve pH determinations for each crop plat.

Crop 1930. Pounds of Limestone Applied per Acre.

	0	600	1200	1800	2400	3000	3600	4200	4800
Corn	5.0	5.4	5.7	5.9	6.2	6.4	6.5	6.7	6.8
Wheat	5.0	5.4	5.6	5.9	6.1	6.3	6.5	6.6	6.8
Sweet clover	5.0	5.4	5.6	5.8	6.2	6.4	6.6	6.8	6.9
Soybeans	5.1	5.3	5.7	5.8	6.1	6.2	6.4	6.5	6.7
Rye	5.1	5.4	5.6	6.8	6.1	6.3	6.5	6.7	6.8
Alsike clover	5.0	5.4	5.7	5.9	6.2	6.4	6.6	6.7	6.8
Potatoes	5.0	5.4	5.5	5.7	6.0	6.2	6.3	6.6	6.7
Barley	5.0	5.4	5.6	5.9	6.1	6.4	6.5	6.7	6.9
Red clover	5.1	5.4	5.6	5.8	6.2	6.4	6.6	6.7	6.9

Table No. 13. A comparison of the average pH determinations made throughout the twelve month period with each crop plat with pH determinations taken on the same plats in 1928.*

Plat crop.	Pounds of Limestone Applied per Acre.								
	0	600	1200	1800	2400	3000	2600	4200	4800
Corn 1928	5.6	6.6	6.2	6.6	6.7	6.4	6.4	7.0	6.6
Corn 1930	5.0	5.4	5.7	5.9	6.2	6.2	6.5	6.7	6.8
Wheat 1928	5.7	5.5	6.0	6.2	6.6	6.4	6.8	7.2	7.4
Wheat 1930	5.0	5.4	5.6	5.9	6.1	6.3	6.5	6.6	6.8
S.clover 1928	5.5	5.4	5.7	6.2	6.2	6.3	6.6	7.0	7.0
S.clover 1930	5.0	5.4	5.6	5.8	6.2	6.4	6.6	6.8	6.9
Soybeans 1928	5.5	5.4	6.2	6.2	6.6	6.8	7.0	7.4	7.2
Soybeans 1930	5.1	5.3	5.7	5.8	6.1	6.2	6.4	6.5	6.7
Rye 1928	5.8	5.6	6.2	6.4	6.2	6.4	6.4	7.2	7.4
Rye 1930	5.1	5.4	5.6	5.8	6.1	6.3	6.5	6.7	6.8
A.clover 1928	5.2	5.2	6.2	6.0	6.6	6.8	7.0	6.8	7.4
A.clover 1930	5.0	5.4	5.7	5.9	6.2	6.4	6.6	6.7	6.8
Potatoes 1928	5.2	5.4	5.4	6.0	5.8	6.6	6.8	7.2	7.3
Potatoes 1930	5.0	5.4	5.5	5.7	6.0	6.2	6.3	6.6	6.7
Barley 1928	5.9	6.6	6.6	6.6	6.4	6.8	7.0	7.2	7.4
Barley 1930	5.0	5.4	5.6	5.9	6.1	6.4	6.5	6.7	6.9
R.clover 1928	4.7	4.8	5.8	5.4	5.7	6.2	5.4	6.8	7.0
R.clover 1930	5.1	5.4	5.6	5.8	6.2	6.4	6.6	6.7	6.9

* Determinations in 1928 made by- F. S. Glassett. (25)

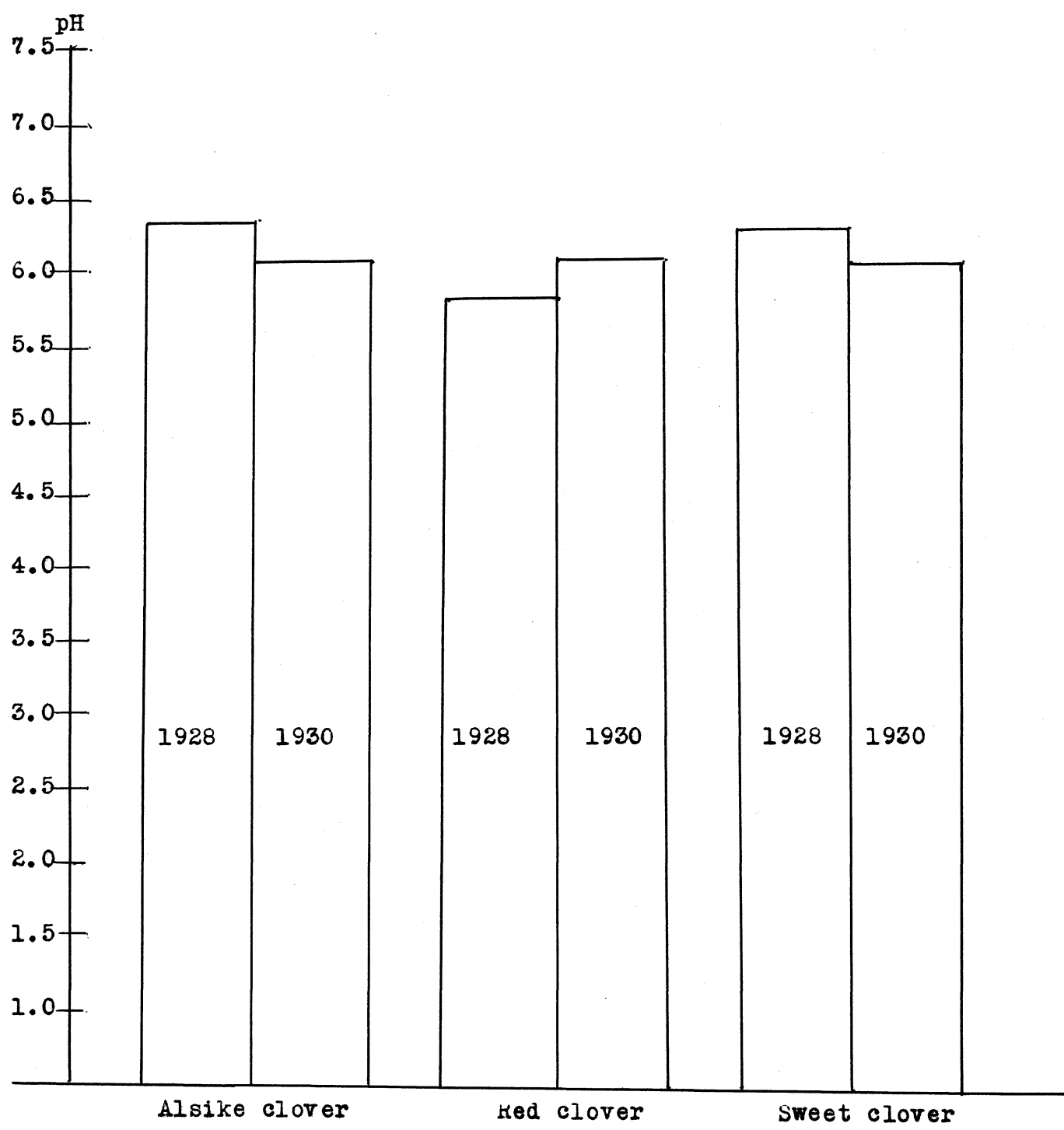


Fig. No. 1. A comparison of the pH determinations made in 1928 and 1930-31 for the Alsike clover, Red clover and Sweet clover plats.

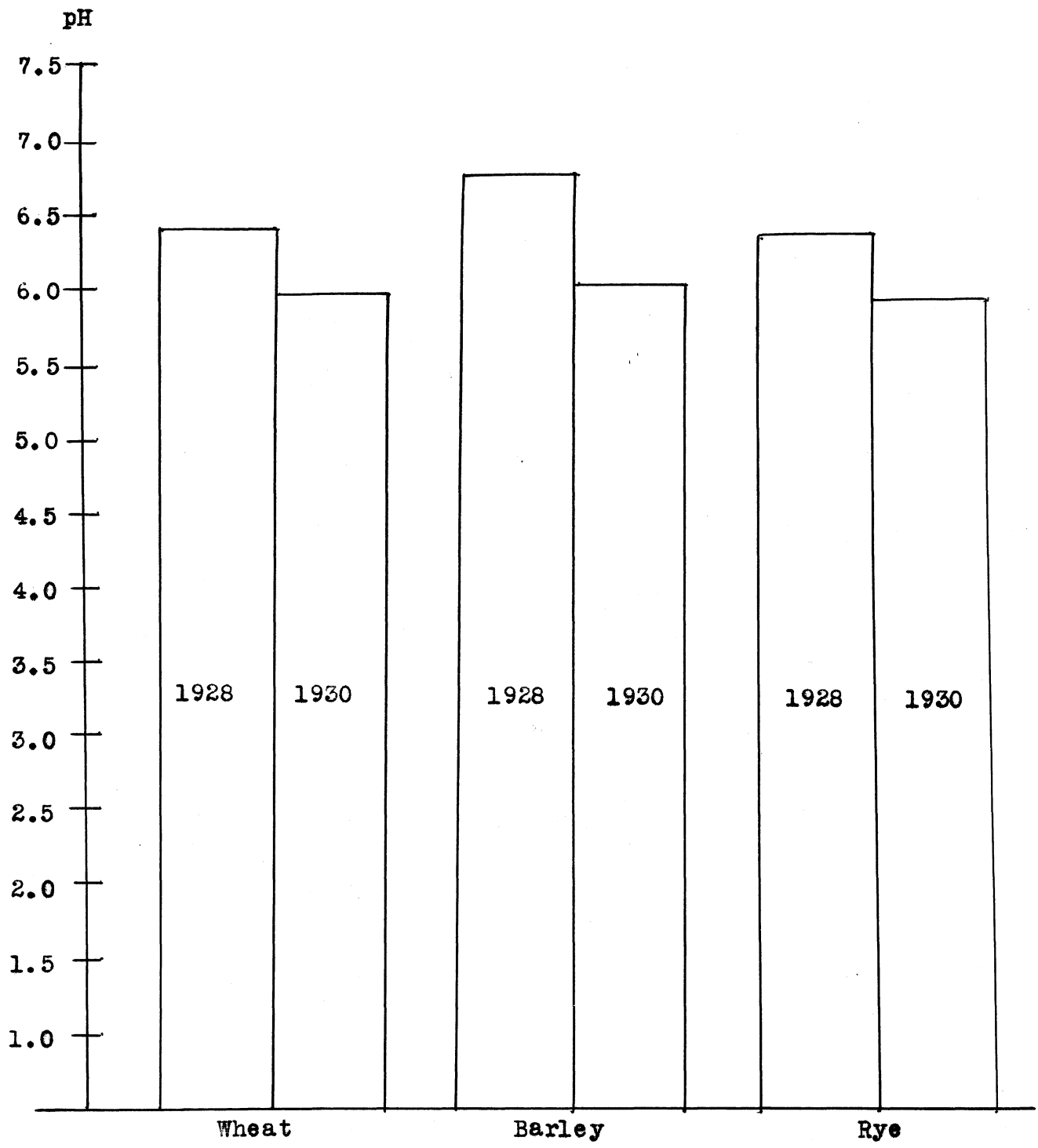


Fig. No. 2. A comparison of the pH determinations made in 1928 and 1930-31 for the wheat, barley and rye plats.

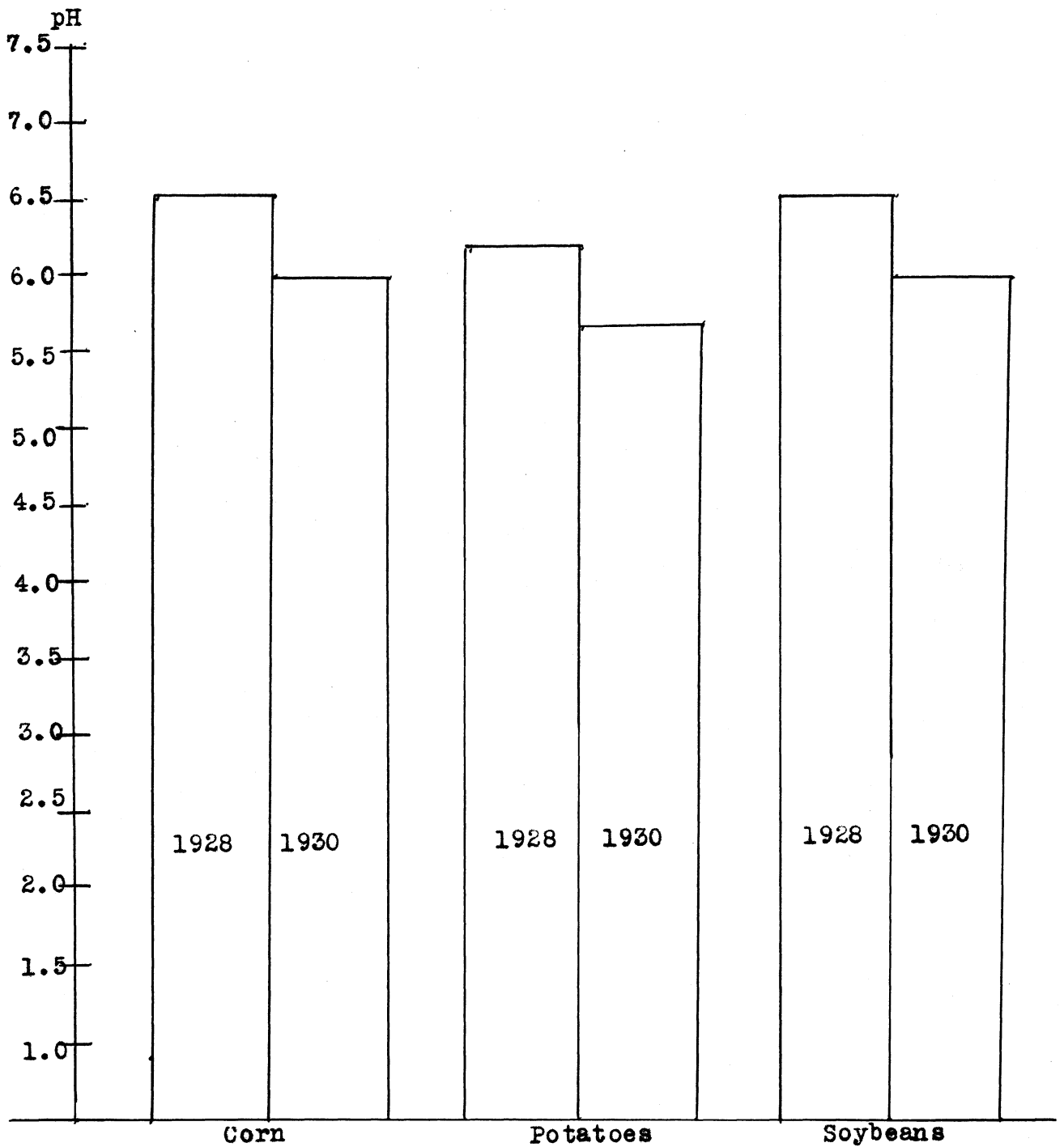


Fig. No. 3. A comparison of the pH determinations made in 1928 and 1930-31 for the Corn, Potatoes and Soybeans plats.

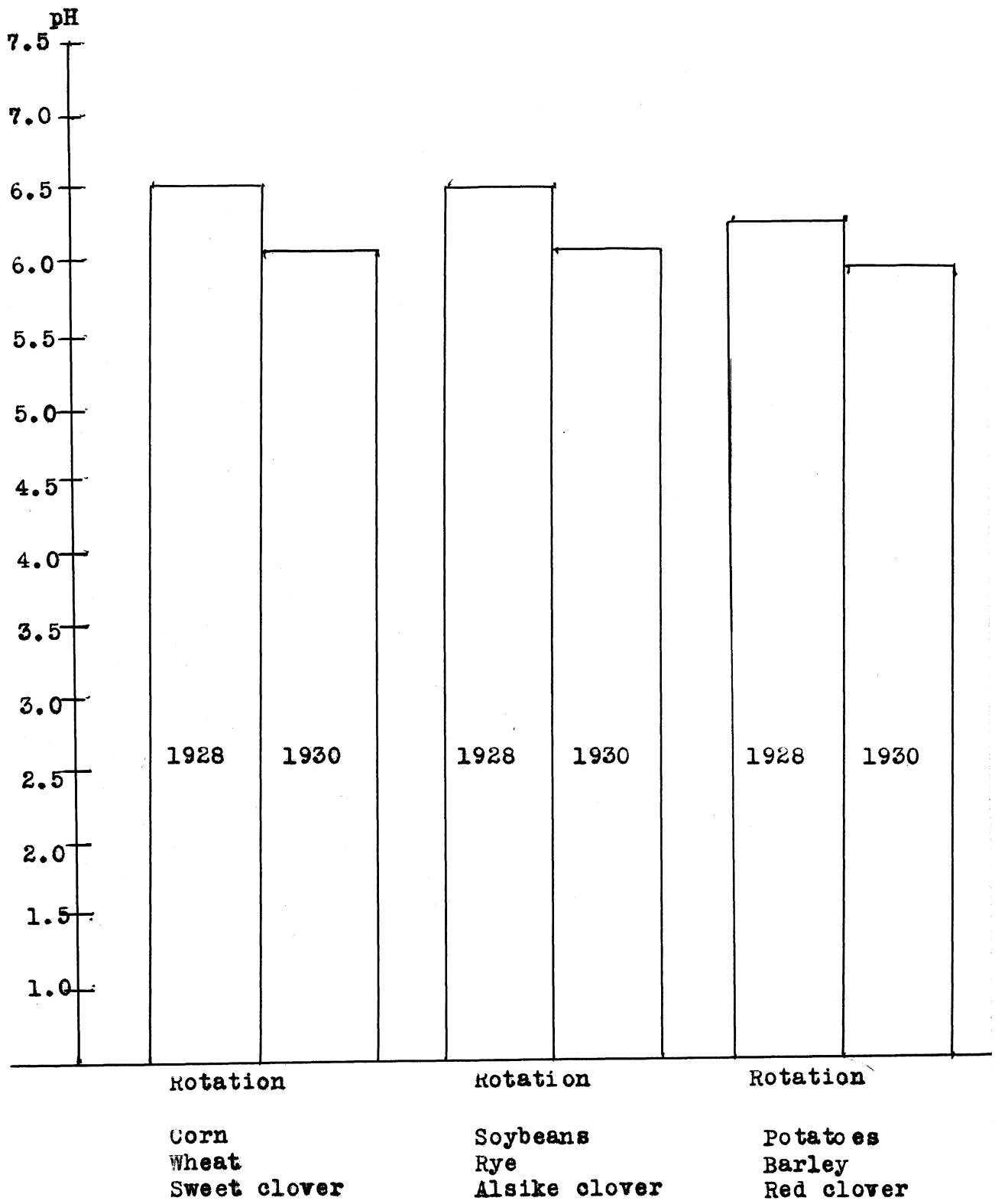


Fig. No. 4. A comparison of the pH determinations made for each of the three crop rotations in 1928 and in 1930-31.

THE CROP YIELDS IN RELATIONSHIP TO pH AND LIME APPLICATIONS.

In an effort to study relationships between the crop yields, soil reaction, and the lime applications, the average pH for the twelve month period and the average crop yields for each plat since the experiment was started have been tabulated and are given in Table No. 15 and shown graphically in Figs. 5 to 13 inclusive. Table No. 16, is based on the average pH determinations and the 1929 crop yields.

RESULTS

In considering the relationship of the pH values to the crop yields and lime applications the question at once comes up, which crop yields should be used as a basis of comparison? Should it be the average of the crop yields, since the experiment started, or should it be the yields for the current year? Unfortunately for this paper, while we have the crop yields for the entire period we have only the determinations for one year. Again the crops were a failure in that year. Since the pH determinations are changing from year to year the average of the crop yields is hardly a fair basis from which to draw conclusions. The pH determinations as well as crop yields should be kept each year over a period of several years and a study of the organic content of the soil and other factors which affect soil reactions should be made in order to draw any definite conclusions. However, a review of literature on the subject and a study of the data show that a relationship does exist.

Table No. 15. Comparison of average yield and average pH for different crops grown on plats which received increasing amounts of lime.

Crops in bushels or tons per acre.	Rates of Applying Ground Limestone.									
	0	600	1200	1800	2400	3000	3600	4200	4800	
Corn, ave. 7 yrs.	26.13	26.07	33.26	32.84	33.17	34.28	36.18	31.44	29.57	
Average pH	5.0	5.4	5.7	5.9	6.2	6.4	6.5	6.7	6.8	
Wheat ave. 6 yrs.	9.48	9.10	9.75	10.96	11.33	11.92	11.03	10.55	9.90	
Average pH	5.0	5.4	5.6	5.9	6.1	6.3	6.5	6.6	6.8	
S. clover ave. 5 yrs.	.20	.88	1.12	1.40	1.64	1.86	1.78	1.52	1.64	
Average pH	5.0	5.4	5.6	5.8	6.2	6.4	6.6	6.8	6.9	
Soybeans ave. 6 yrs.	1.53	1.58	1.75	1.87	1.89	1.93	1.88	1.79	1.76	
Average pH	5.1	5.3	5.7	5.8	6.1	6.2	6.4	6.5	6.7	
Rye Ave. 7 yrs.	16.86	16.44	18.16	18.24	19.83	20.27	21.62	22.08	21.41	
Average pH	5.1	5.4	5.6	5.8	6.1	6.3	6.5	6.7	6.8	
A. clover ave. 6 yrs.	1.36	1.53	1.68	1.85	1.75	1.81	1.81	1.80	1.76	
Average pH	5.0	5.4	5.7	5.9	6.2	6.4	6.6	6.7	6.8	
Potatoes ave. 5 yrs.	42.57	44.68	40.68	40.84	31.15	37.42	36.88	36.78	28.85	
Average pH	5.0	5.4	5.5	5.7	6.0	6.2	6.3	6.6	6.7	
Barley ave. 7 yrs.	16.54	18.13	21.83	21.93	23.88	21.15	22.24	22.73	22.82	
Average pH	5.0	5.4	5.6	5.9	6.1	6.4	6.5	6.7	6.9	
R. clover ave. 6 yrs.	1.17	1.33	1.88	1.95	1.98	1.89	1.92	1.83	1.79	
Average pH	5.1	5.4	5.6	5.8	6.2	6.4	6.6	6.7	6.9	

Table No. 16. Comparison of 1929 yields with the average 1930 pH values for crops grown on plats which received increasing amounts of lime.

Crop yields in bus. Rates of Applying Ground Limestone.

or tons per acre.

	0	600	1200	1800	2400	3000	3600	4200	4800
Corn	16.25	25.63	36.25	37.50	28.12	43.75	44.31	33.12	30.00
Average pH	5.0	5.4	5.6	5.9	6.1	6.3	6.5	6.6	6.8
Wheat	7.6	8.0	6.0	9.2	12.2	10.1	8.1	6.0	4.8
Average pH	5.0	5.4	5.6	5.8	6.2	6.4	6.6	6.8	6.9
S. clover	.30	1.08	1.80	2.30	2.50	2.62	2.64	1.52	1.64
Average pH	5.0	5.4	5.7	5.9	6.2	6.4	6.5	6.7	6.8
Soybeans	1.78	1.90	1.95	2.25	2.74	2.50	2.54	1.62	2.00
Average pH	5.1	5.4	5.6	5.8	6.1	6.3	6.5	6.7	6.8
Rye	27.80	29.17	30.83	31.17	29.17	28.33	31.66	32.06	30.31
Average pH	5.0	5.4	5.7	5.9	6.2	6.4	6.6	6.7	6.8
Alsike	.27	.98	1.12	1.20	1.11	1.14	1.10	1.20	1.10
Average pH	5.1	5.3	5.7	5.8	6.1	6.2	6.4	6.5	6.7
Potatoes	86.66	91.66	75.00	65.00	60.00	48.33	56.66	50.00	41.66
Average pH	5.0	5.4	5.6	5.9	6.1	6.4	6.5	6.7	6.9
Barley	12.26	20.31	20.94	25.00	27.65	25.77	25.00	23.26	24.22
Average pH	5.1	5.4	5.6	5.8	6.2	6.4	6.6	6.7	6.9
Red clover	.86	.82	1.24	1.38	1.56	1.56	1.60	1.56	1.38
Average pH	5.0	5.4	5.5	5.7	6.0	6.2	6.4	6.6	6.7

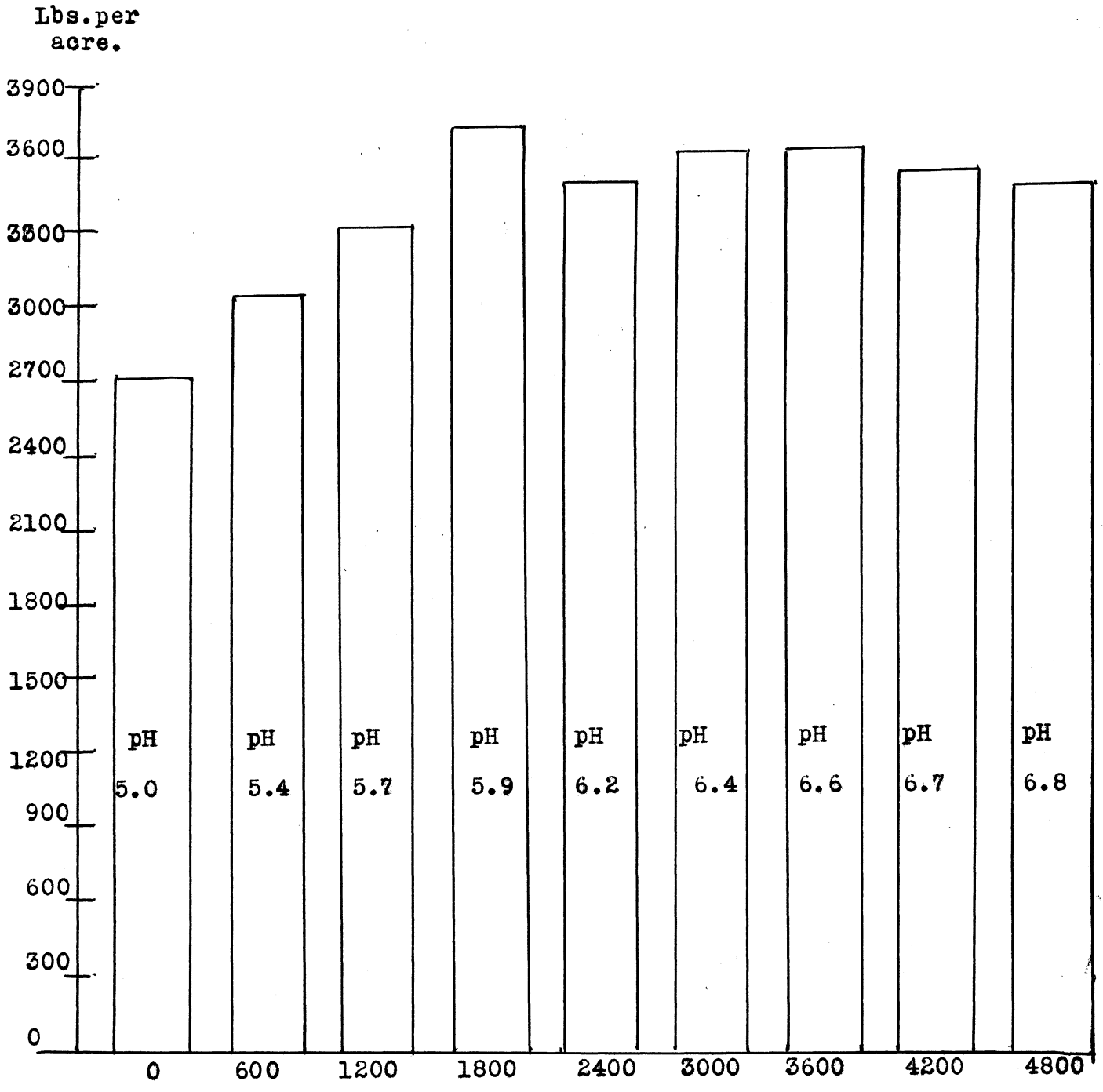


Fig. No. 5. The average Alsike clover yields from each of the Lime plats together with the average pH determinations.

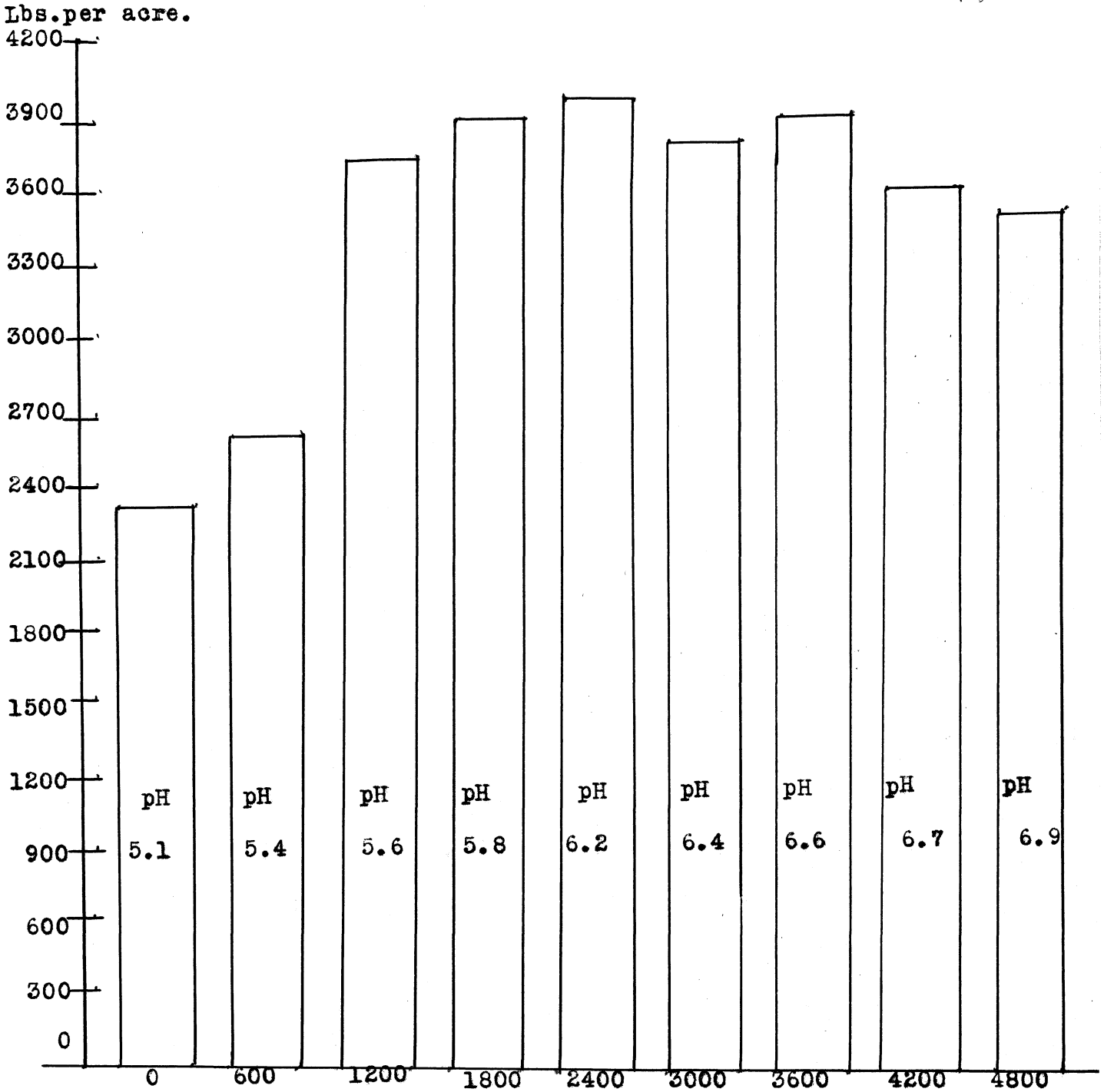


Fig. No. 6. The average red clover yields from each of the Lime plats together with the average pH determinations.

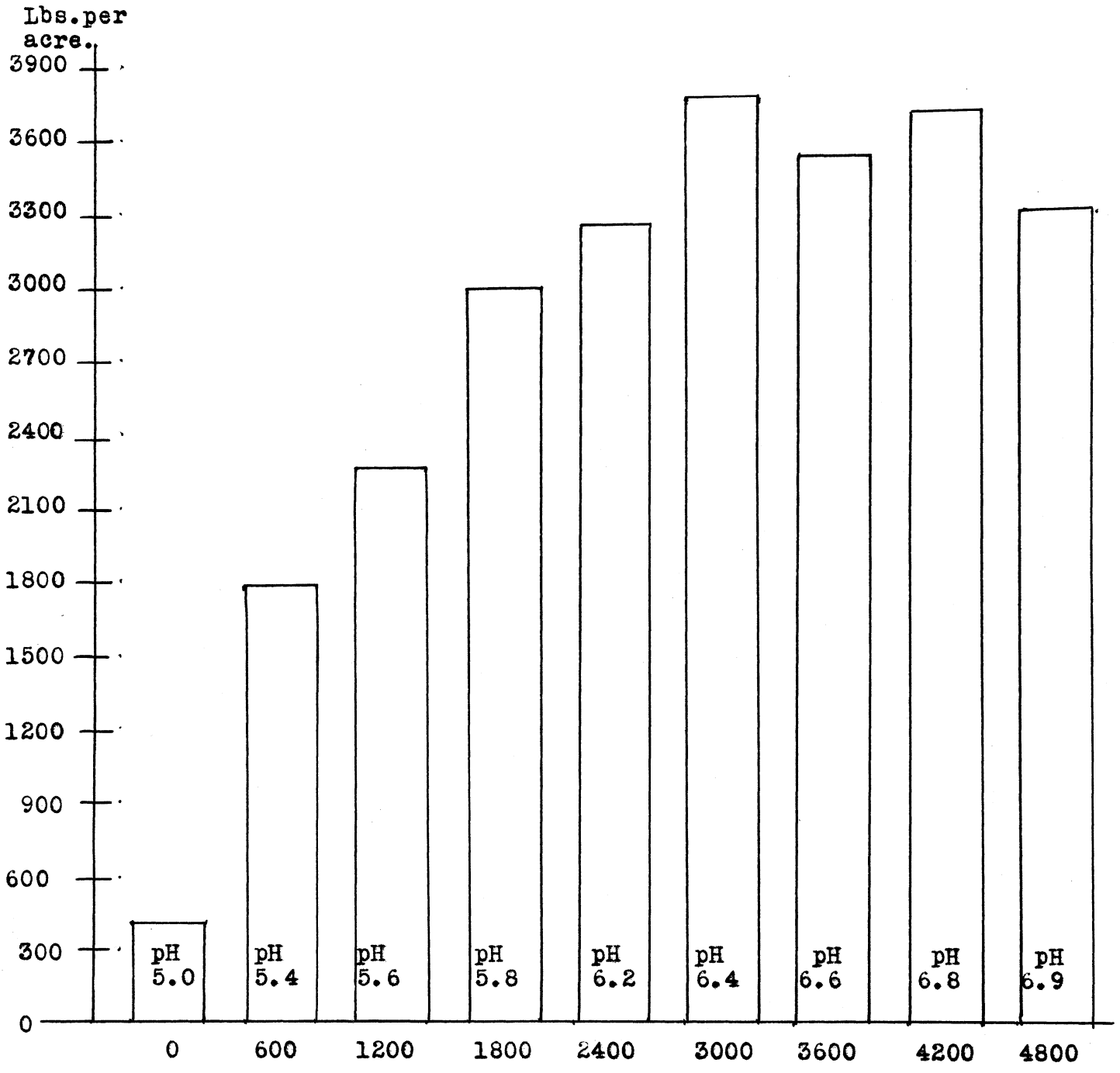


Fig. No. 7. The average sweet clover yields from each of the Lime plats together with the average pH determinations.

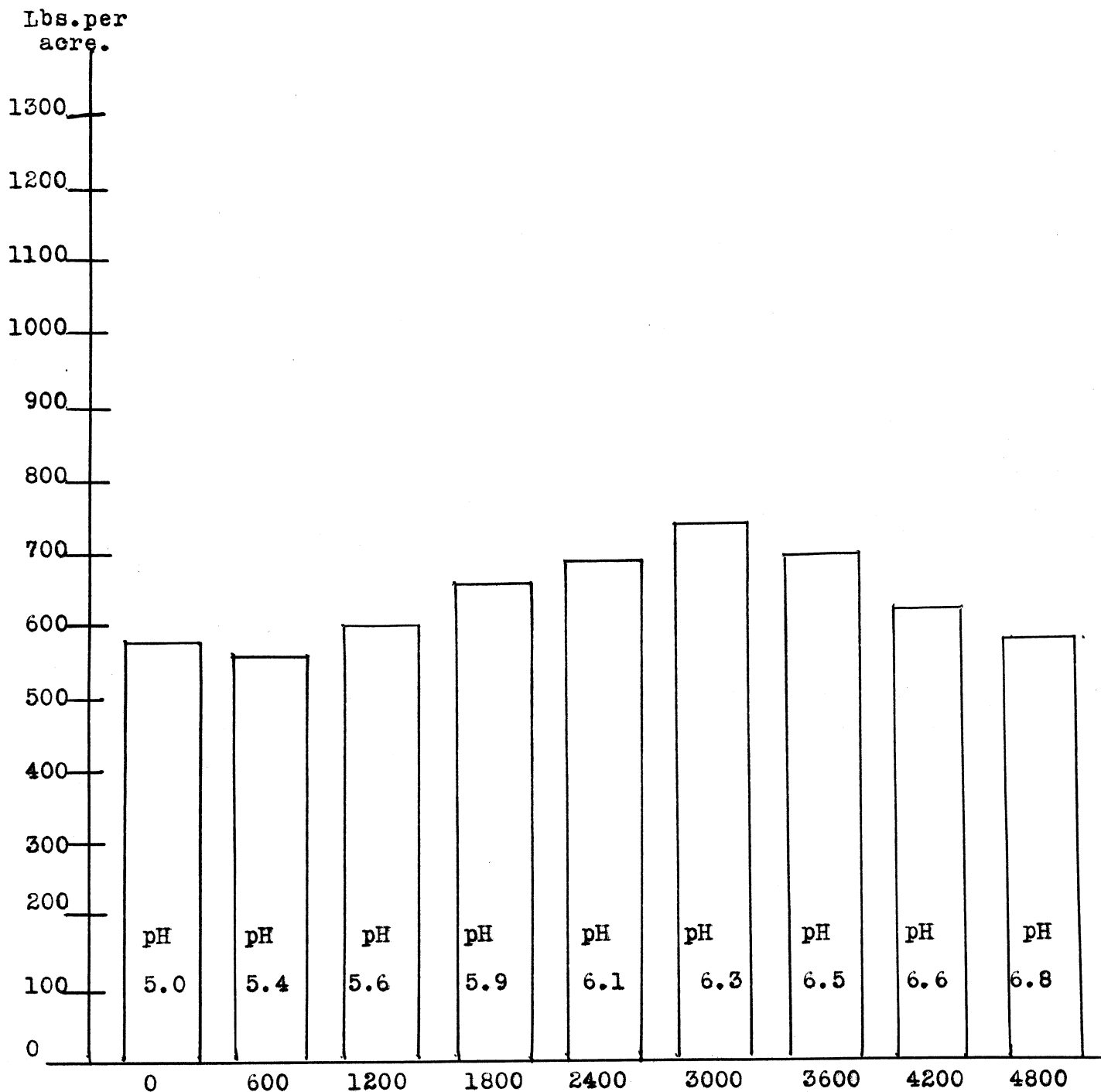


Fig. No. 8. The average wheat yields from each of the
Lime plats together with the average pH determinations.

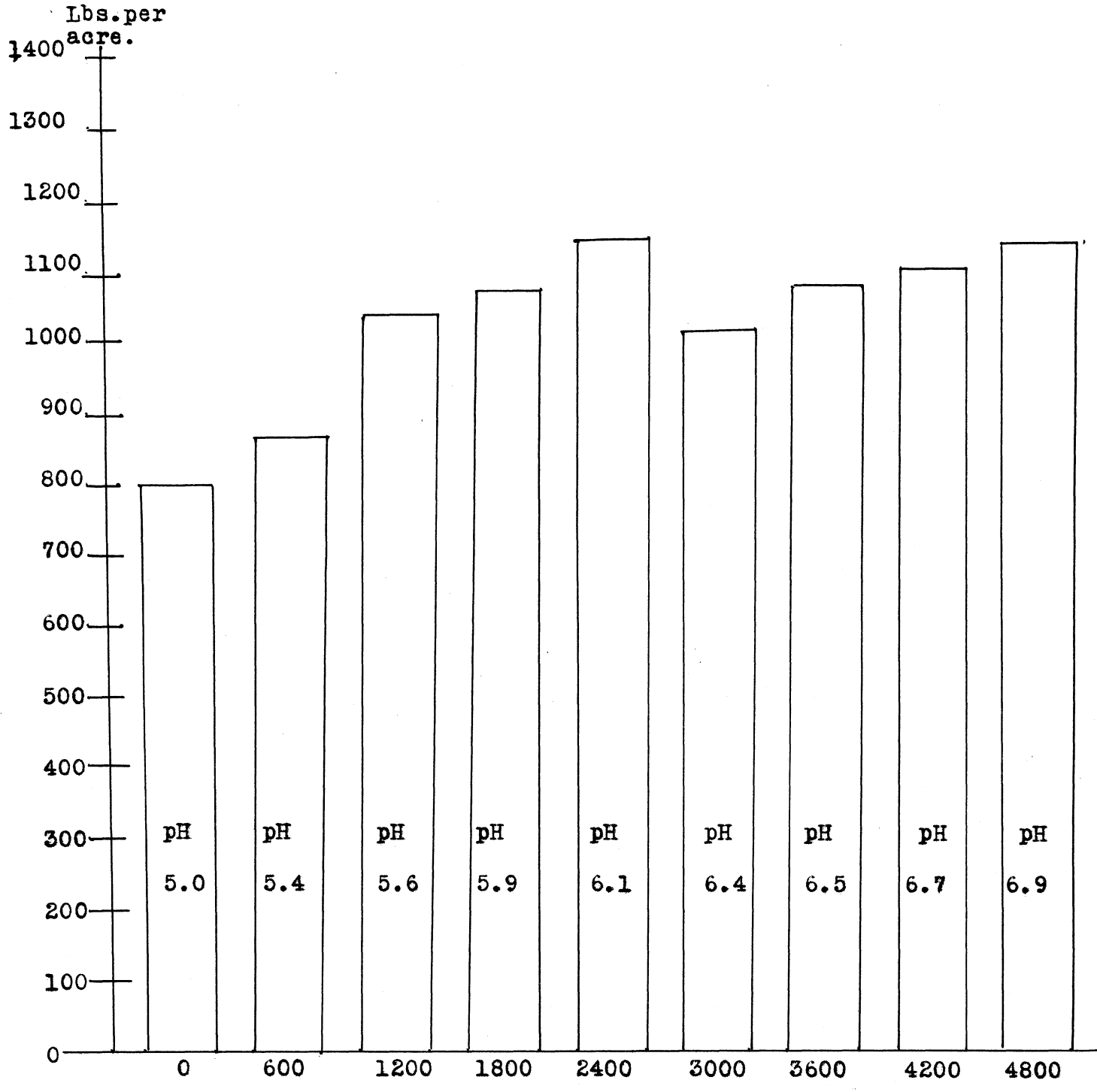


Fig. No. 9. The average barley yields from each of the Lime plats together with the average pH determinations.

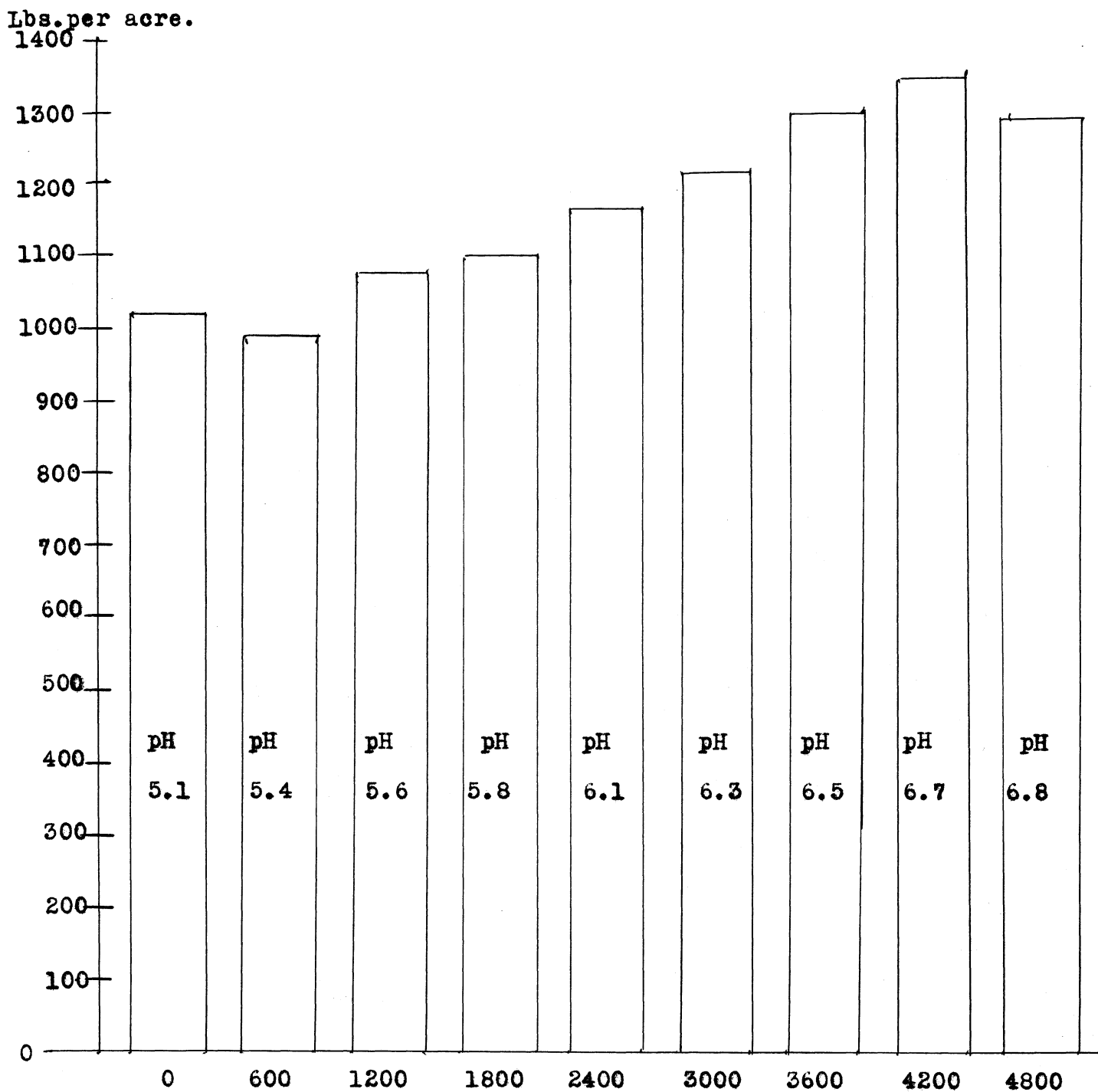


Fig No. 10. The average Rye yields from each of the
Lime plats together with the average pH determinations.

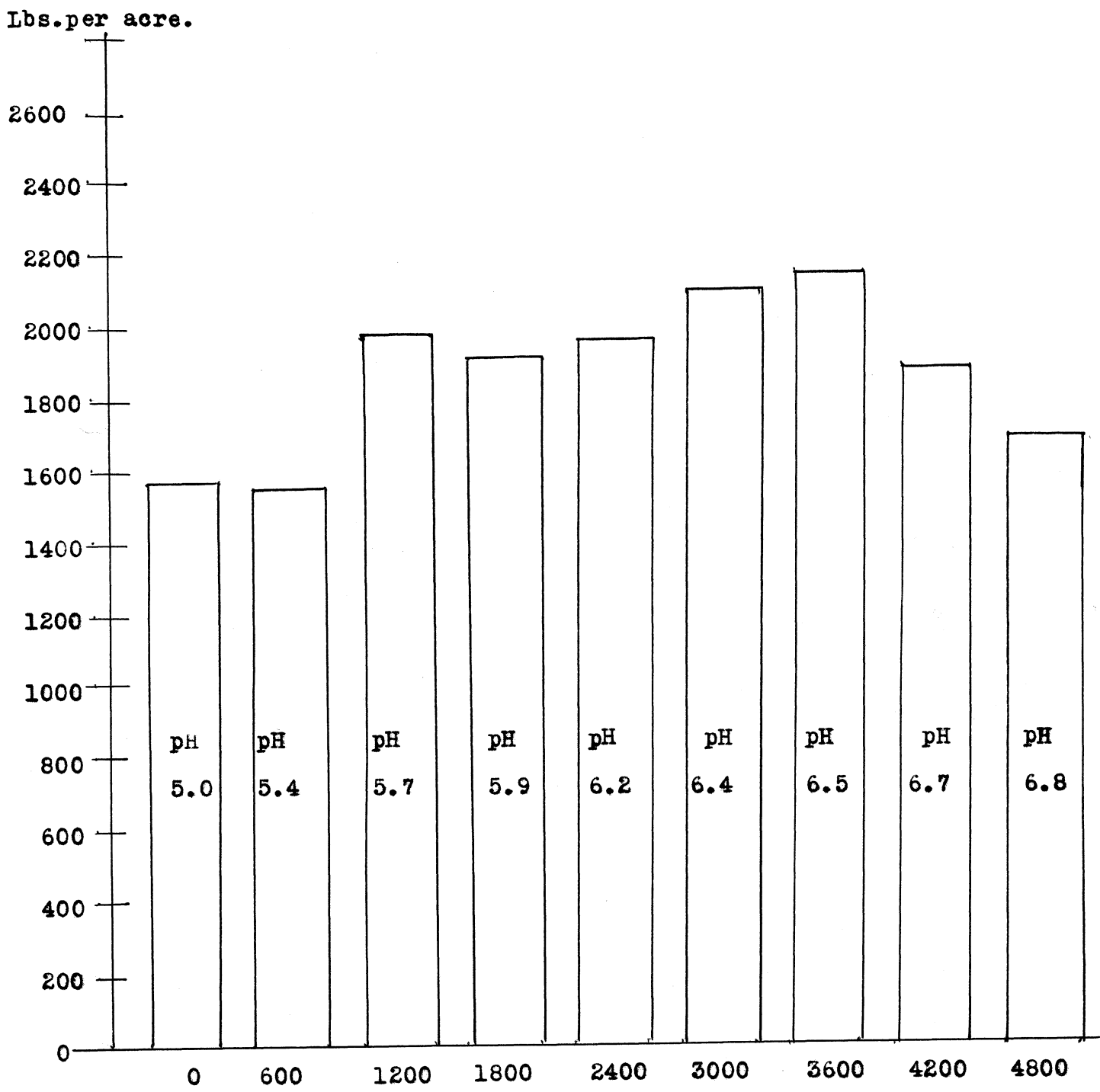


Fig. No. 11. The average corn yields from each of the Lime plats together with the average pH determinations.

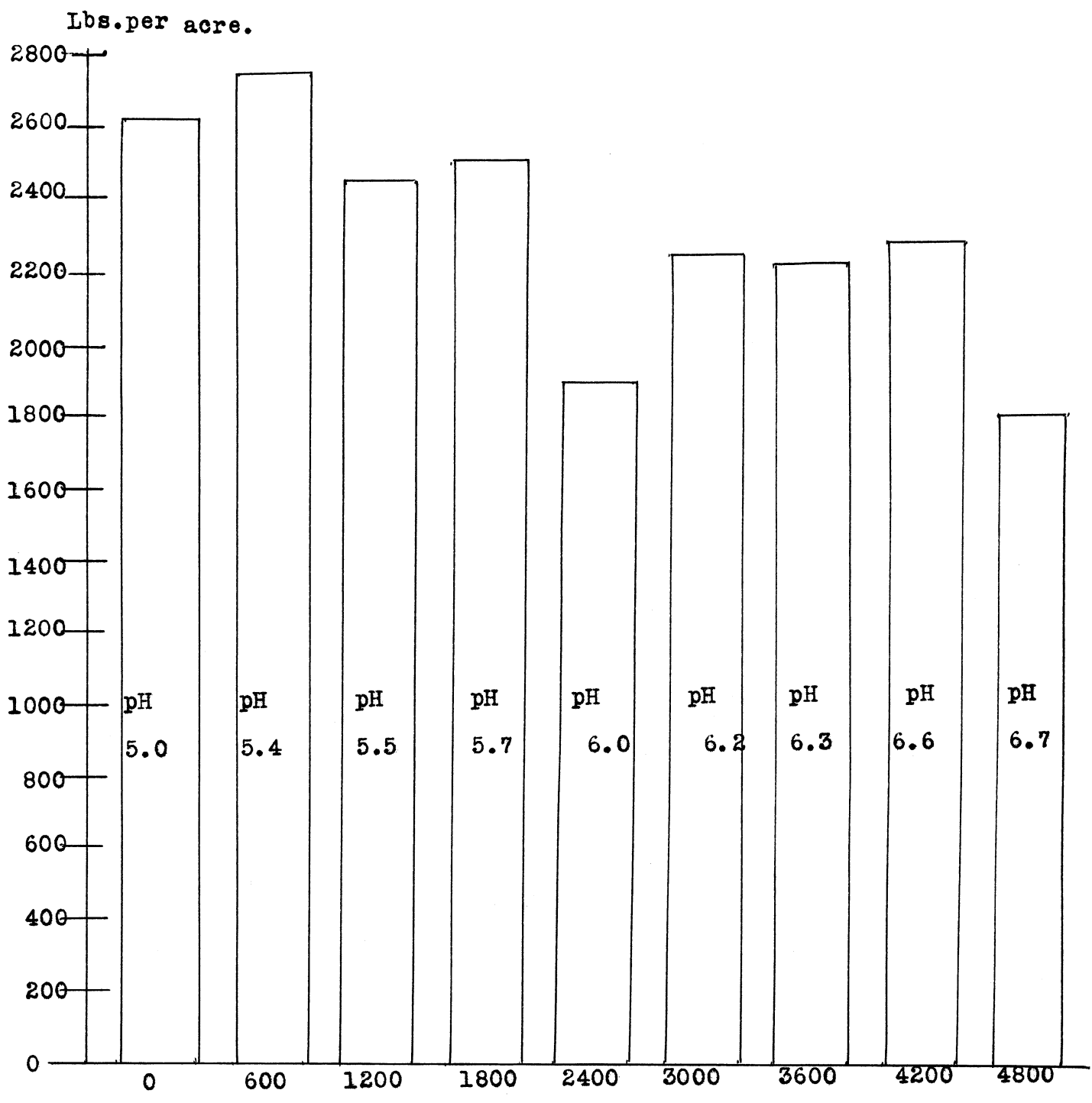


Fig. No. 12. The average Potato yields from each of the Lime plats together with the average pH determinations.

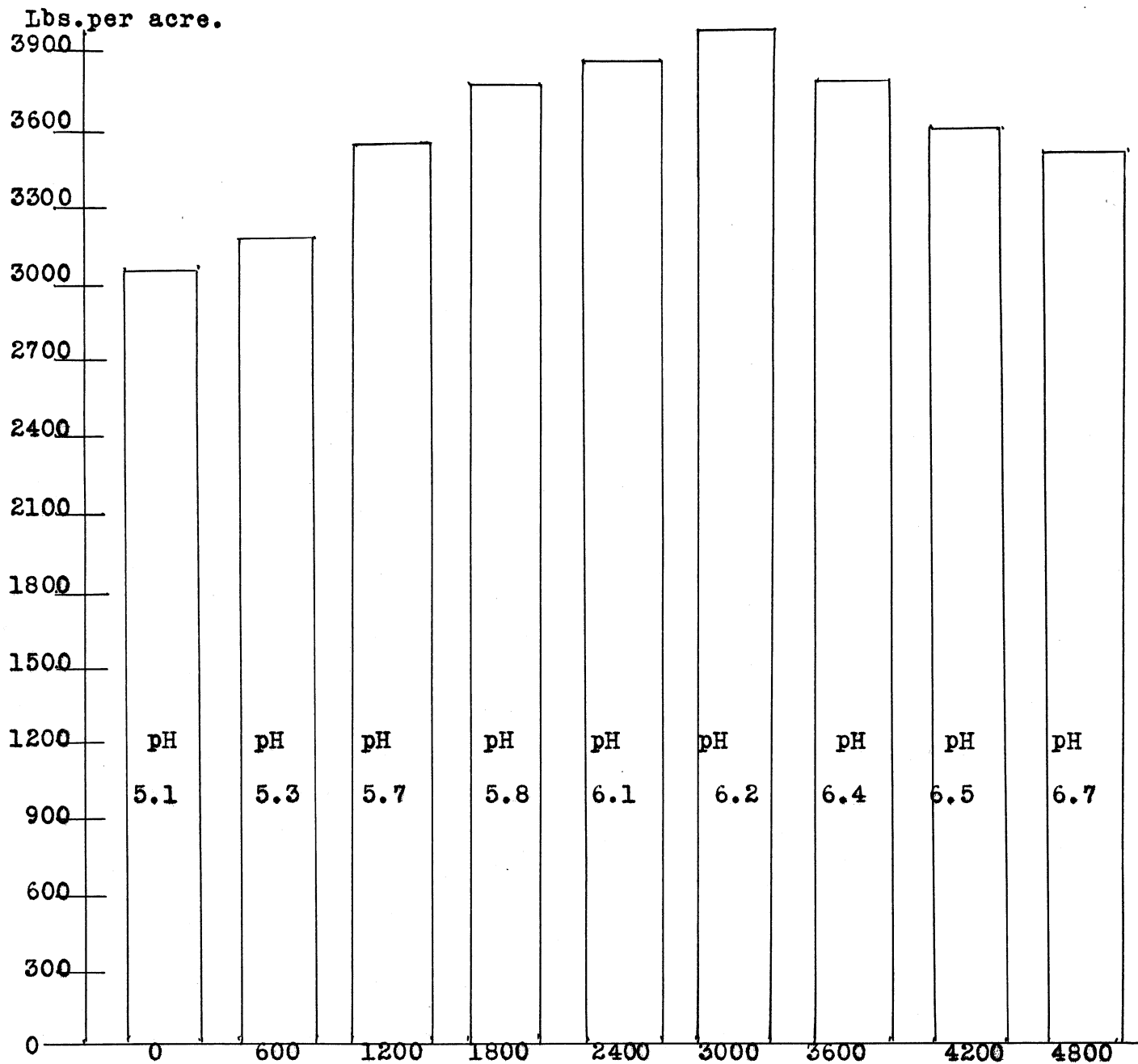


Fig. No. 13. The average soybean yields from each of the Lime plats together with the average pH determinations.

THE OPTIMUM SOIL REACTION AS SHOWN BY THE pH VALUE FOR EACH OF THE CROPS GROWN.

It is well known that crop plants differ in their ability to tolerate acid conditions. Thus, the clovers and alfalfa are regarded as being very sensitive to acidity, while rye, potatoes and tobacco will tolerate acid conditions fairly well. In an effort to determine the optimum soil reaction for the nine crops grown, both the average crop yields since the experiment was started and the 1929 crop yields are used.

RESULTS

A study of Table No. 17, based on the average yields and Table No. 18, based on the 1929 yields show a very much higher pH and lime requirement for the 1929 crop yields than for the average crop yields. This is what would be expected since the plats are becoming more acid each year. It would appear from a review of the crop yields each year, that while the maximum yields are on plats which receive medium lime applications for the first few years after the lime is applied, that maximum yields, for most of the crops, shift towards the heavier application plats as the time elapses from the application date. With the pH changing each year and with only one years determinations it is difficult to draw a relationship between the crop yield and soil reaction. However, the 1929 yields and the pH determinations made in 1930-31 should give a fairly accurate idea as to the optimum soil reaction for each of the crops grown.

Figs. 14 to 16 inclusive show a comparison of the maximum and minimum yields of each crop grown with the pH determinations and lime applications. With two exceptions the minimum yields are found on the plats which receive no lime. Sweet clover shows the greatest variation between the maximum and minimum yield, and potatoes show the lowest lime requirement of any of the crops grown.

Table No. 17. The optimum soil reaction as shown by the pH value, for each of the crops grown, based on average crop yields.

Crop	pH	Lime Application per acre.
Corn	5.7	1200
Wheat	5.9	1800
Sweet clover	6.4	3000
Soybeans	5.8	1800
Rye	6.1	2400
Alsike clover	5.9	1800
Potatoes	5.4	600
Barley	6.1	2400
Red clover	6.2	2400

Table No. 18. The optimum soil reaction as shown by the pH value, for each of the crops grown, based on the 1929 yields.

Crop	pH	Lime Application per acre.
Corn	6.4	3000
Wheat	6.2	2400
Sweet clover	6.5	3600
Soybeans	6.3	3000
Rye	5.9	1800
Alsike clover	5.8	1800
Potatoes	5.4	600
Barley	6.2	2400
Red clover	6.3	3600

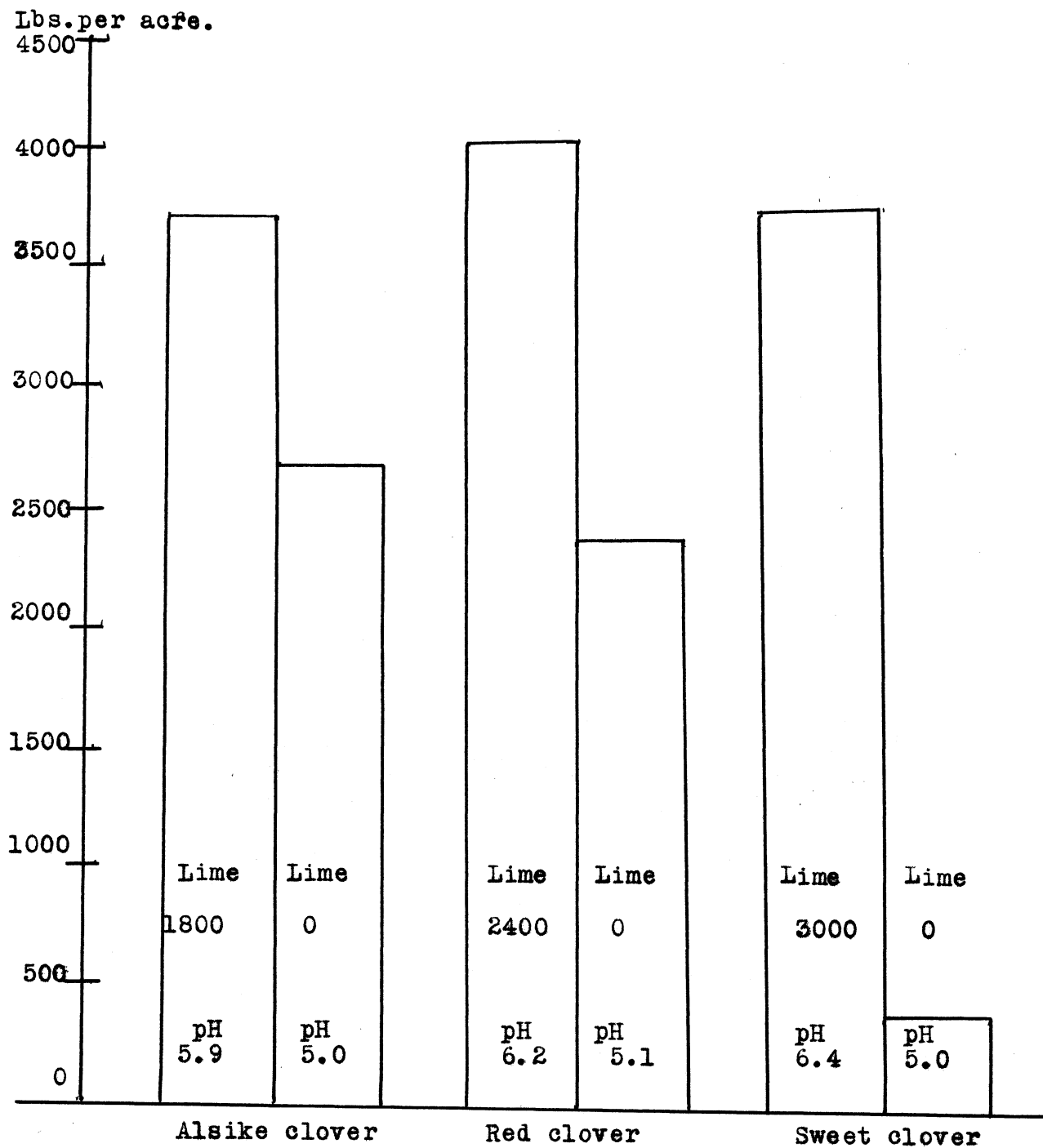


Fig. No. 14. A comparison of the maximum and minimum yields of Alsike clover, Red clover and Sweet clover with the average of the pH determinations and lime applications for each plat.

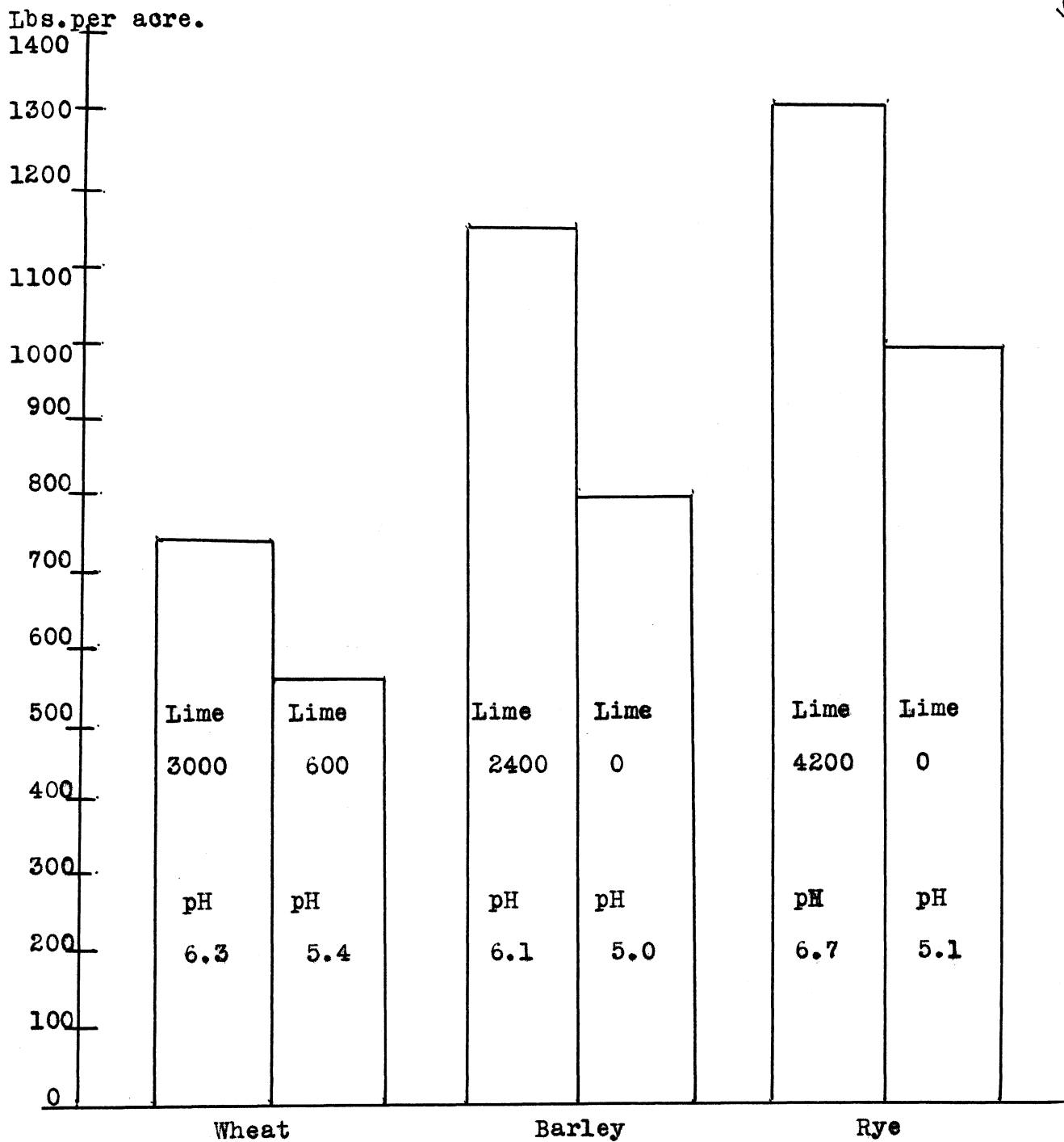


Fig. No. 15. A comparison of the maximum and minimum yields of wheat, barley and rye with the average of the pH determinations and lime applications for each plat.

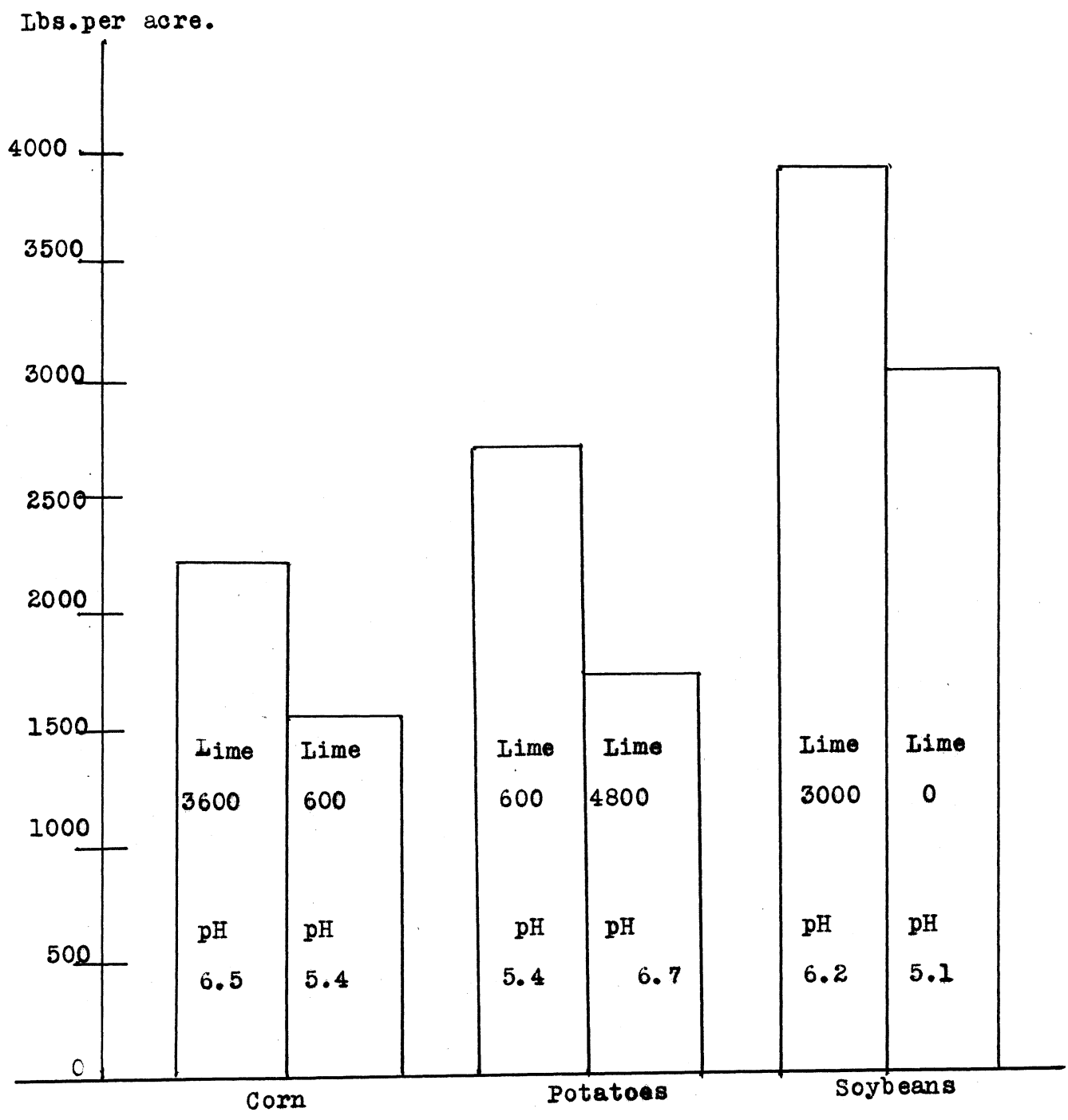


Fig. No. 16. A comparison of the maximum and minimum yields of corn, potatoes and soybeans with the average of the pH determinations and lime applications for each plat.

SUMMARY AND CONCLUSIONS.

(1) The experiment as a whole showed that pH determinations may be made at any time throughout the year with assurance of being reliable as a relative indicator of lime requirement.

(2) A comparison of the pH determinations made in 1928 with those made in 1930-31, show that the plats have become more acid.

(3) The pH values of the soil paralleled the quantity of lime applied. Where no lime was applied the soil was found to be very acid, but increasing applications of lime brought the reaction gradually to the neutral point.

(4) There appears to be a definite relation between pH and crop yield. For each crop the yields increased up to a certain pH; beyond which they decreased again. The optimum pH for the crops grown in the experiment reported here are as follows;

Alsike clover	5.8
Red clover	6.3
Sweet clover	6.5
Soybeans	6.3
Wheat	6.2
Barley	6.2
Rye	5.9
Corn	6.3
Potatoes	5.4

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