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RESPONSE OF POTATOES TO FERTILIZERS

by Ford S. Prince, Paul T. Blood, and Thomas G. Phillips

During the past twelve years investigations concerning the response of potatoes to various fertilizer elements have been under way in New Hampshire. The first test of this nature was started in 1928 on the Jackson farm in East Columbia, near Colebrook, New Hampshire. A second similar experiment was set up on the Lane farm, in Chichester, near Pittsfield, New Hampshire in 1933.

Both experiments embodied a three-year rotation of potatoes, oats, and hay. In the Jackson farm trial, timothy was included in the hay mixture while on the Lane farm clover only was seeded, although both red and alsike clovers were used. The Jackson field has run through four courses of this three-year rotation, while the Lane farm has run through two; and in both cases, potatoes, oats, and hay have been grown each year.

Besides fertilizer formulæ and rotation problems, inquiries into certain other phases of potato growing have been made. The use of magnesium and boron in the fertilizer mixture, the relationship between scab occurrence and soil pH; and lately, the influence of variety as well as fertilizer variations on potato quality have been studied.

Studies of organic matter have also been made on soil samples taken at the beginning and end of the trials in both cases in order to note the effect of such rotations on the maintenance of organic matter; and, in addition, to find out what influence the different treatments have had on this important soil component. It is our purpose in this bulletin to discuss these researches, to present data covering any significant facts that have developed, and to draw such conclusions as seem warranted from the work that has been done.

Description of Soils

In view of progress made in the soil survey of New Hampshire, we are able to classify and describe the soils of the Jackson and Lane farm fields. In the forthcoming report of the Coos County soil survey, B. H. Williams, Division of Soil Survey, United States Department of Agriculture, describes the Worthington loam soil found on the Jackson farm thus:

"**Worthington loam.** The Worthington loam in cultivated fields has a brown or dark brown surface soil 7 to 8 inches deep (plow depth), which is mellow and inclined to a weak crumb structure. This rests upon yellowish-brown loam. This, at about 11 to 12 inches depth, passes into olive or greenish-yellow loam of the same structure, which, at 14 or 15 inches, passes into greenish-gray, firm, but friable till. The soil throughout is strongly acid.

"Under forest conditions the Worthington loam has a definite podzol profile development. The gray surface layer beneath the forest litter or duff is 1 to 2 inches thick, which changes to a dark brown or coffee-brown layer about 1 inch thick; and this, in turn, to a rust-brown layer about 2 inches thick, before passing into the yellowish-brown subsoil. Under cultivation the gray and brown layers lose their identity through mixing, and the brown or dark brown plowed soil rests upon the yellowish-brown subsurface or upper subsoil. Roots and moisture penetrate the soil with ease, and there is always a sufficient moisture supply for crop development.

"Worthington loam is confined to the eastern part of the town of Columbia, central parts of Colebrook and Stewartstown, and extends to a degree into Clarksville. Approximately four square miles of this soil is mapped on the more mild relief of the rolling upland areas in this section. It is developed from schist till that has some calciferous or limy schist, and siliceous limestone incorporated. It occurs mainly east of a lime belt that begins a few miles to the southeast of Colebrook village, and extends northward across Colebrook, Stewartstown and Clarksville.

"The movement of the glacier from northwest to southeast across this lime belt incorporated a considerable amount of the lime carrying rocks with the till. The visible easterly and southerly limits of this lime-influence is the boundary that separates the Worthington soils from the Berkshire soils.

"The Worthington loam is nearly all in crops. On it, together with some of the smoother Berkshire and Greensboro soils, is developed the most stable agriculture of the rolling upland sections of the county and of the state. Although not as well adapted to growing of grains as some of the valley farms because it is 1200 to 2000 feet above sea level, it grows other crops just as well, and potatoes on this soil give higher average yields. Located here are many dairy-potato-growing farms.

"Farming is rather intensive, includes relatively short rotations, heavy use of manure and commercial fertilizer, growing of legumes for hay, and liming of land when not used for potato growing. Because of favorable soil and climatic conditions, there is a tendency of some farms to take on a specialized potato-farm aspect, with dairying as a sideline to furnish an outlet for forage crops and as a source of manure to keep up soil fertility.

"The section in which the Worthington and associated soils occur is relatively free from disease and insect pests that affect potatoes; and a considerable amount of the crop is certified for sale as seed to other less favored sections.

"Timothy and clover hay yields 1½ to 2 tons or more per acre, mixed soybean and millet hay about the same, and grains cut for hay slightly less. Grain harvested is negligible, but in favorable years yields well. Potatoes, under average farm practice using 1 ton of 20-unit fertilizer, yield from 200 to 300 bushels per acre; when planted close with extra fertilizer, yields of 400 bushels are common and maximum yields are above 500 bushels per acre."

Paxton loam, found on the Lane farm field, is typical of many southern New Hampshire potato-growing areas since this soil occupies the rounded hilltops of much of this area. The soil is one of the brown podzolic group, and has been described by soil survey men as follows:

"Paxton soils occur with Brookfield soils, and have developed where the glacier overrode the yellow till causing it to be compact and platy. The most common occurrence is on the glacial form known as drumlin.

"The surface 6 inches is brown or dark brown loam, and the subsoil to the depth of about 18 or 20 inches is yellowish-brown firm loam to silt loam, and between about 20 and 30 inches the subsoil is friable, yellow, fine sandy loam. The substratum is compact, platy, fine sandy till. It is hard but breaks readily into firm angular plates about ¼ inch thick and ½ inch across."

It is this compact substratum that imparts good waterholding capacity to the Paxton loam, but at the same time probably renders it somewhat more susceptible to erosion than if the subsoil were loose and more permeable to water.

These two soils are similar with respect to crop producing ability, although they are derived from slightly different kinds of rock. Worthington is formed from a fine grained schist with some lime influence; and Paxton from a mica schist which under the same climatic conditions would probably develop into a more acid soil.

The Worthington soil of the Jackson farm lies at an elevation of 1700 feet and is roughly about 125 miles north of the Lane field which has an elevation of only 650 feet above sea level. Under the climatic conditions that prevail, the Jackson field has been more heavily leached so that the soil, unlimed, has a pH value of about 4.8, whereas the pH of the Lane soil is about 5.2 unlimed. Lower prevailing soil temperatures on the Jackson field permit the accumulation of more organic matter than on the Lane field.

Rotations

The rotations followed in these two tests have been very similar. Both fields were divided into plots, and the plots arranged in blocks so that potatoes, oats, and hay could be grown each year in the three-year rotation. All the fertilizer used was applied to the potato crop, the oats and hay being grown on any residual fertilizer left from the potato crop, and on the plant food these crops might extract from the soil itself.

Lime was applied to certain series on the Jackson field at the rate of two and four tons per acre, not immediately preceding the potatoes, but to the oats at the time the oats and clovers were seeded. Only one application of lime at this rate was made during the first twelve years, but at the end of the six year period lime was applied to other plots at the rate of 500 and 1000 pounds per acre. Again there was but one application made during the second six-year period. On the Lane field, lime was used at the rate of 500 and 1000 pounds, but only once on the limed plots during the six-year period studied.

Timothy was used with the clover seedings on the Jackson farm, while on the Lane field an alsike and red clover mixture was used.

The rotation on the Jackson field prior to 1928 was typical for the region, and consisted of one or two years in potatoes followed by a hay-seeding in oats, which was then left in hay for seven or eight years. During the life of the hay stand, it was customary to top-dress the field with manure every year, or at least every two years.

The previous rotation on the Lane field was similar to that of the Jackson farm, one year or at the most two years in cultivated crops, then seeding to oats, clover, and grass. Ordinarily no top-dressing was practiced on the Lane field either with manure or fertilizers; hence the hay crop usually "ran out" more quickly and had to be plowed sooner than on the Jackson field. It will be noted, therefore, that the three-year rotation under consideration in our experimental work was somewhat shorter than those previously practiced on the same fields.

The primary purpose of these trials was to determine the effects of the three principal plant food nutrients on the growth of potatoes to find out, if possible, whether any changes in the fertilizer formulae now on the market should be made to increase yields or to lower production costs. Accordingly, a 4-8-7 fertilizer was chosen as standard treatment and all check plots received one ton of fertilizer per acre of this analysis. In the first two courses of the rotation on the Jackson farm, potatoes were grown without nitrogen and with double nitrogen in the 0-8-7 and 8-8-7 series, without phosphorus and with double phosphorus in the 4-0-7 and 4-16-7 series, also with no potash, limited potash and increased potash in the 4-8-0, 4-8-3 and 4-8-10 series.

During the first two courses of the rotation on the Jackson farm, two years' results are not included in the summary. The season of 1928 was very wet at planting time and one section of the plots developed a very poor stand of potatoes. Hence, the 1928 figures are not included in the summary. During the season of 1933, a promising early variety of potatoes was grown, but this variety behaved so differently from Green Mountains, the kind that had previously been produced, that it has been deemed advisable to omit the 1933 data. They will be discussed separately, however.

Table I is a summary, therefore, of four comparable years of the first six in the Jackson farm trials.

TABLE I. 4-year average yields of potatoes on the Jackson farm, 1929-32.

Treatment	Yield	P. E.*	Difference from Check	P. E.
1 Ton 4-8-7 Check	386	± 4		
" 0-8-7	360	± 9	— 26	± 10
" 8-8-7	400	± 8	14	± 9
" 4-0-7	286	± 10	—100	± 11
" 4-16-7	432	± 8	46	± 9
" 4-8-0	237	± 10	—149	± 11
" 4-8-3	356	± 7	— 30	± 8
" 4-8-10	418	± 11	32	± 12

*Probable error (P. E.) in this and other tables where yields are concerned was computed by Bessel's formula: $\sqrt{\frac{ED_2}{N(n-1)}} \times .6745$ in which ED_2 refers to the sum of the squares of the deviation from mean and n to the number of plots.

In interpreting probable error, we have considered that to be significant, a difference must be at least three times its probable error.

See H. H. Love, "The Role of Statistics in Agronomic Experimentation," Sci. Agri. 5: 84-92.

P. E. of the difference is calculated by the formula: $\sqrt{(P.E.)^2 + (P.E.)^2}$ where P.E. in each case is the probable error of the individual determinations from which the difference is derived.

In discussing the data in Table I, it seems desirable to state that a great deal of work has been done by research workers and farmers on the fertilizer formulæ, to attain the most desirable balance of nutrients as well as to determine desirable amounts of plant food.

It is pretty generally recognized that the potato crop is a weak feeder, and that generous amounts of available plant food should be provided for the crop during the short period of its growth. This fact has led to the use of a ton or more of fertilizer per acre in New England. Most commercial potato growers now use an equivalent of about 2400 pounds per acre of fertilizer approximating 20 units, or almost half that weight of 40 unit or double strength materials. Twenty-four hundred pounds of a 5-8-7 fertilizer carries 120 pounds of nitrogen, 192 pounds of phosphoric acid, and 168 pounds of potash.

Brown (5) reports four years' work from Connecticut in which maximum yields were obtained from fertilizer which supplied approximately 100 pounds per acre of nitrogen, 180 pounds of phosphoric acid and 120 pounds of potash. In a previous report Brown (5) and Slate stated that for maximum yields on land not recently manured, 80 pounds of nitrogen, 100 to 120 pounds of phosphoric acid, and 80 pounds of potash should be applied to each acre. These results are cited to show that in the same state, and even in the same locality, varying amounts of plant food have been found to produce maximum yields. It seems fair to state that the native fertility of the soil, the amount of organic matter, the capacity of the soil to hold and yield water when needed to the growing crop, the acidity of the soil, and the supply of rare elements, are factors that, under certain conditions, may affect the amount of plant food that should be used for maximum results.

During the first World War, scarcity and high costs of potash led to investigations concerning how much potash should be used for optimum yields of potatoes. In general these tests have indicated that the best ratio of nitrogen, phosphoric acid, and potash in the potato fertilizer approximates a 2-4-3. Yet the most common potato fertilizer formula in Aroostook county today is a 2-4-5. It carries considerably more potash than experiments have revealed to be necessary. Continued short rotations, or some other factors, probably serve to change conditions sufficiently to warrant the greater use of potash under present Maine farming systems.

Thompson (25) et al. note that in New York state "the most-used analysis on upland soils in the principal potato growing areas is 4-8-7. Except on the very lightest soils, the 4-8-7 carries more potash than is justified. The 4-12-4 and the 5-10-5 mixtures should continue to be encouraged in most situations in western and central New York." Thus while it appears that in Maine a high potash formula is required, New York research points to the use of a high phosphorus formula.

Hartwell (15), in arranging twenty crops from low to high in their response to the three principal plant food elements, places the potato in the low grouping for nitrogen, but in the medium grouping for both phosphoric acid and potash. Morgan (17) groups all crops into four classes—low, medium, high, and very high, according to their responses to the three nutrients; and places the potato in the high grouping for nitrogen and potash, and in the very high grouping for phosphoric acid. Morgan's work is given particularly for Connecticut conditions.

There is no doubt that the potato is an exacting crop for plant food and that the use of large amounts of fertilizer is justified. The proper ratio and balance of nutrients might well vary with different soils and under varying climatic conditions as well as the total amount of plant food.

Table I indicates the response secured by varying the fertilizer formula on the Jackson farm field in northern New Hampshire. A study of the data indicates that the omission of any one of the elements reduces potato yields, the decrease for omitting nitrogen, phosphoric acid, and potash amounting to 26, 100 and 149 bushels, respectively. Increasing the potash to three per cent in the 4-8-3 series, increased the yield over the 4-8-0 series by 119 bushels and brought the yield to within 30 bushels of the check plot series. All the decreases are statistically significant except for the plots where the nitrogen was omitted.

Doubling the nitrogen of the fertilizer (8-8-7) gave an increase of but 14 bushels; doubling the phosphoric acid (4-16-7) increased the yield 46 bushels, while increasing the potash (4-8-10) resulted in an increase of 32 bushels per acre. Among these increases only that for phosphoric acid is significant, although the 32 bushel increase for extra potash just fails in this respect. This indicates that on this soil, and under the conditions of this experiment, more phosphoric acid and probably more potash than is found in one ton of a 4-8-7 fertilizer could be used to advantage on the potato crop.

In changing over the Jackson farm experiment in 1934, the plots receiving a 4-8-10 formula during the previous period were scheduled to receive a 4-8-14 fertilizer during the next two courses of the rotation. The treatment for the 4-16-7 plots was unchanged, while the plots which had previously received an 8-8-7 formula received a treatment of 4-16-14 in the new layout, one ton per acre in each case. Yields for the second six-year period are given in Table II.

TABLE II. Six-year average, 1934-39, Jackson farm potato yields.

Treatment	Bu. per acre Yield	Bu. per acre P. E.	Bu. per acre Difference from Check	P. E.
1 Ton 4-8-7 Check	371	± 6		
" 4-16-7	397	± 11	26	± 13
" 4-8-14	373	± 15	2	± 16
" 4-16-14	420	± 15	49	± 16

It will be noted that the check plot-yields fell slightly below those of the previous period. This may be due to climatic conditions, and it may also be associated with a decreasing organic matter supply.

Increased yields due to additional phosphoric acid (4-16-7) are considerably smaller than those reported in Table I, yet the data are consistent although the increase is not significant. Plots receiving double potash (4-8-14) registered but a small increase, while those getting both additional phosphoric acid and potash gave a significant increase of 49 bushels per acre.

With respect to the plots receiving increased phosphoric acid (4-16-7), it may be noted that the results follow farm experience quite closely, since demonstrations on land which had previously been cropped extensively to potatoes and had received large quantities of fertilizer, have not shown as large increases from additional phosphoric acid as land which is less frequently plowed and less heavily fertilized.

It is quite possible, too, that potatoes grown on high land are more responsive to increased phosphoric acid than potatoes on land at a lower altitude because more leaching has occurred on high lands. These soils at higher altitudes apparently have a stronger fixing power for phosphates and require more phosphoric acid than is found in the ordinary potato fertilizer formula.

A carefully checked test on the R. N. Johnson farm, Walpole, New Hampshire, in which different phosphatic carriers were used, was conducted in 1934. The soil of this farm lies at 1400 feet elevation and according to rapid soil tests exhibited a high aluminum fraction, indicating a strong fixing power for soluble phosphates. The potato crop was fertilized uniformly at the rate of one-half ton of an 8-16-16 formula per acre at planting time, and prior to planting plots were laid out and top-dressed with phosphorus carriers which were then harrowed in. Eight hundred pounds per acre of the three materials indicated in Table III were used on separate plots and the potatoes yielded as follows:

TABLE III. Johnson farm test of phosphatic fertilizers, 1934.

	Yield per acre bu.	Gain bu.
Check — ½ T. 8-16-16	333.9	
½ T. 8-16-16 + 800 ℔ raw rock phosphate	352.2	18.3
½ T. 8-16-16 + 800 ℔ basic slag	362.4	28.5
½ T. 8-16-16 + 800 ℔ 16% super	368.3	34.4

These data coincide to some extent with the Jackson farm tests, and seem to point to a need for a high phosphorus formula as well as phosphatic fertilizers that are readily available on soils that lie at high altitudes.

With respect to the behavior of varieties other than Green Mountain to changes in the fertilizer formula, the yields of the White Triumph, grown in 1933, are here reported.

TABLE IV. Fertilizer effects on White Triumph potatoes on Jackson farm in 1933.

Treatment	Yield	P. E.	Difference from check	P. E.
1 Ton 4-8-7 Check	235	± 9		
" 4-0-7	60	± 12	−175	± 15
" 4-16-7	296	± 9	61	± 13
" 4-8-0	96	± 4	−139	± 10
" 4-8-3	200	± 3	− 35	± 9
" 4-8-10	197	± 22	− 38	± 24

The interesting thing in the response of this variety is that omission of phosphoric acid caused a greater decrease in yield than omission of potash. Increasing the potash to three per cent (4-8-3), increased the yields around 100 bushels per acre over no potash, but an increase up to ten per cent of potash did not increase yields over the three per cent formula. These facts, and the rather large gain in the series for which the phosphoric acid was doubled (4-16-7), indicate that this variety is particularly responsive to phosphoric acid and much more sensitive to variations in this plant nutrient than to potash. This may be true of other varieties.

Lane Farm Trials

Results for fertilizer variations on the Lane Farm are presented in Table V.

TABLE V. Six-year average yields of Lane farm potatoes with varied fertilizers, 1933-38.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 Check	239	± 5		
" 0-8-7	231	± 6	— 8	± 8
" 8-8-7	250	± 10	11	± 11
" 4-0-7	202	± 12	— 37	± 13
" 4-16-7	258	± 9	19	± 10
" 4-8-0	184	± 9	— 55	± 10
" 4-8-14	259	± 10	20	± 11

In comparing these data with those in Table I it will be noted that total yields are much lower and that variations due to the omission or increase of the elements are considerably smaller. The only statistically significant difference in Table V is the decrease of 55 bushels in yield of the 4-8-0 series. It will be further noted that the decreases for omission of elements are in the same relative order as in Table I, and further, that extra nitrogen (8-8-7) gave less response than either of the other two series in which elements were increased.

In spite of lack of statistical significance in the data, there has been a consistency in results over the years which should lend some weight to their value. Probably no one who had seen the plots during their growth would doubt that the plots that did not receive phosphoric acid would yield as well as those receiving normal fertilization. Likewise, it was apparent each year that the additional phosphoric acid and potash greatly stimulated the growth of vines and foliage, and this additional leaf surface is generally translated into tubers later on. Over a period of six years, therefore, it seems safe to conclude that the Lane farm data support those of the Jackson farm in pointing to the need for slightly more phosphoric acid and potash than is found in a 1-2-2 or similar ratio.

Lime in Potato Rotations

Lime was used in both these experiments at varying rates to determine if lime could be used in a potato rotation, how much could safely be applied, and what effect the lime would have on potato yields as well as on the hay crops that follow.

In the first six-year period on the Jackson farm, lime was applied at the rates of two and four tons per acre on separate series. This was not applied directly for potatoes, but after the potatoes were grown and prior to seeding the land to the hay crop. Hence, there are but three years' data on lime effects on potato yields reported here. Ground limestone was used in these tests.

TABLE VI. Effects of lime on 3-year average yields of Jackson farm potatoes, 1930-193_

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 Check	389	± 6		
" 4-8-7 + 2 T. Lime	369	± 7	− 20	± 9
" 4-8-7 + 4 T. Lime	401	± 11	12	± 13
" 4-8-0 + 2 T. Lime	196	± 9	−193	± 11

It will be noted here that a decrease in yield was shown with the two tons of lime application, and an increase with four tons, although neither difference is significant. In the treatment in which two tons of lime were applied with the fertilizer carrying no potash, the difference of −193 bushels is highly significant. In comparing the yields in this series with the 4-8-0 treatment, Table I, it is apparent that the yield of potatoes in limed plots was depressed more than on the series with no lime, the actual yield for the 4-8-0 series during the three years covered by Table VI being 223 bushels per acre, or an increase on the plots which had no lime over those which received lime of 30 bushels per acre. This difference was consistent through the years, the unlimed plots always outyielding the limed ones.

It would appear from these facts that lime serves to depress potash availability, and since potash was omitted from the fertilizer altogether, this depression was serious enough to cause rather large yield differences.

A great deal of potato scab developed on these plots limed at the two and four ton rates.

Upon revamping the Jackson farm experiment in 1934, plots were included which received 500 and 1000 pounds of ground limestone per acre, while all the plots which had previously received two and four tons of limestone were continued during the next six-year period. On the four ton plots, however, aluminum sulphate and sulphur were used on the halves of each plot as acidulating substances to counteract the effects of lime in promoting scab. Yield records are given in Table VII on all these limed series.

TABLE VII. Effects of lime and fertilizer on 6-year average yields of Jackson farm potatoes, 1934-1939.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 Check	371	± 6		
" 4-8-7, 500℔ Lime	383	± 11	12	± 13
" 4-8-7, 1000℔ Lime	364	± 13	− 7	± 14
" 4-8-7, 2 T. Lime	373	± 11	2	± 13
" 4-8-7, 4 T. Lime	355	± 12	− 16	± 13
" 4-8-0, 2 T. Lime	215	± 14	−156	± 15

The chief interest, perhaps, in using lime in a potato rotation is to encourage better hay growth and to produce more crop residues or green manures to plow under. While a great deal more clover was produced on all the limed plots and increases in hay yields were rather large, it does not appear that the lime benefited the potato crop either directly or indirectly through increasing crop residues. Perhaps it should again be noted that in both these tests the first hay crop was cut and removed, but the second crop was plowed under. In both these tests the 500 and 1000 pound lime applications were applied but once in the six year period, while the two and four ton applications (Jackson farm) were applied once in twelve years. Serious scab resulted from the heavy applications, but no appreciable effect upon scab was noted from the smaller applications in either case.

With particular reference to the Jackson farm, it seems that, although the average pH value of the soils of the check series is about 4.8, this acidity is not sufficiently strong to reduce potato growth, but it does limit clover and hay yields tremendously as will later be shown.

This seems to support the work of Smith (22) who states that there were no significant differences in potato yields on plots between pH range of 4.8 and 7.1. He also states that yields declined below pH 4.8, and this fact is corroborated by our work on certain plots on Jackson farm on which Ammo Phos was used in large amounts, causing the soil to become somewhat more acid.

These plots received a fertilizer made up of equal quantities of Ammo Phos "A" and Nitrate of Potash, in amounts approximately equalling one ton, and one and one-half tons of 4-8-7 fertilizer. Yields for these plots, over the second six-year period, compared with the check plot series were as follows:

TABLE VIII. 6-year average yields of Jackson farm potatoes with acidifying fertilizer.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 Check	371	± 6		
" D. S. Equiv.	359	± 9	− 12	± 11
1½ Ton D. S. Equiv.	344	± 20	− 27	± 21

While the differences reported are not statistically significant, vine growth has always been inferior to that of the check plots, the foliage having a slightly darker color, along with a bronzing indicative of magnesium hunger. The bronzing was especially marked on the 1½ T. D.S. plots. This would lead us to place some confidence in the decreasing yields under this fertilizer formula even though as much, or more actual plant food was applied.

Clover was practically a failure when these plots were seeded to hay, and the growth of grasses was inhibited as well. Sorrel came into the plots in great abundance during the year they were in hay, indicating that for some reason the soil had become unsuited to hay production. Acidity studies were conducted annually on all the plots and while the pH values of the soils of the D.S. plots are not consistently lower than those of the check treatment, they tend toward a lower pH, the D.S. series in 1939 having a pH of 4.48, and the 1½ T. D.S. a pH of 4.23, while the comparable check plots averaged pH 4.66. It appears, therefore, that the effect of the Ammo Phos on increasing soil acidity along with the greater removal of basic elements, including magnesium, may account for lower potato yields and poor hay growth.

The conclusion seems justified, then, that the Jackson farm soil is at the moment suited to maximum potato growth, but that any material which increases acidity is likely to interfere with full potato yields. Since the soil appears to be at the critical point in this respect, the use of lime is to be recommended in quantities small enough so that they will not encourage potato scab, but in sufficient quantity to give assurance that the soil will not become any more acid than it is at present, and especially so that good hay crops will be produced.

The limed plots on the Lane Farm, like those of Jackson, show no stimulation on the potato crop.

In a test on the Ireland farm, Greenland, New Hampshire, on land limed at different rates and on which soybeans had been grown the previous year and plowed under, potato yields were increased, apparently because of the increased growth of the soybeans due to liming and the subsequent decay of this crop in the soil.

TABLE IX. Effect of lime on yields of Ireland farm potatoes, 1934.

Treatment*	Yield per acre	P. E.	Diff. from no lime	P. E.
No lime	116	± 10		
1 Ton lime	184	± 9	68	± 13
2 Ton lime	189	± 5	73	± 11

*Uniform fertilization except for previous lime applications.

Although the yields were not large, they nevertheless indicate distinct stimulation to the potato crop from the effect of lime on previous soybean growth. Yields of the soybean crop grown in 1933 on this land had been secured by taking square yard samples from each plot in quadruplicate and reducing them to an air dry condition. Because of the interest in this phase the yields of the 1933 soybean crop are given.

TABLE X. Effect of lime on yields of soybeans, Ireland farm, 1933.

Treatment	Yield, Air Dry Wt. per Acre
No Lime	966 lbs.
1 T. Calcium Lime	1661 lbs.
2 T. Calcium Lime	1863 lbs.
2 T. Magnesium Lime	2108 lbs.

Varying Amounts of Fertilizer

During the first two rotations on the Jackson farm, different amounts of fertilizer were applied at rates of one-half ton, one ton, and one and one-half tons of 4-8-7 per acre. Yields are reported in Table XI for these varying amounts of fertilizer.

TABLE XI. Four-year average yields of Jackson farm potatoes with varying amounts of fertilizer, 1933-38.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7	386	± 4		
½ Ton 4-8-7	318	± 8	— 68	± 9
1½ Ton 4-8-7	431	± 13	45	± 14

These data indicate that response is secured for more than one ton of a 4-8-7 fertilizer under the conditions of this test, but show, of course, that additional amounts of fertilizer bring diminishing returns. Both differences are highly significant.

It has already been noted that commercial potato growers in New England now commonly apply more than one ton of fertilizer of a formula such as was used in this experiment. While there are many factors involved, such as the opportunity for producing high yields, due to favorable climate and rainfall, and the possibility of getting a fair price for the crop, which affect the amount of fertilizer that should be used, it would seem that if conditions are favorable, more than one ton of fertilizer can economically be used.

It is interesting to note, however, that the yield for the one and one-half ton application of 4-8-7 is almost exactly the same as for the 4-16-7 treatment (Table I). In this experiment the 4-16-7 formula was made up by using one ton of 4-8-7 and adding to it one-half ton of 16% superphosphate, which, of course, amounts to the equivalent of one ton of 4-16-7 fertilizer. The effectiveness of this formula proved to be just as great as the addition of the extra half-ton of 4-8-7 in the one and one-half ton treatment, but at just about half the extra cost. This lends considerable weight to the idea that the formula, or balance of nutrients, is important for economy in potato production.

High and Low Analysis Fertilizers Compared

In the Lane farm test, high and low analysis fertilizers were compared for the six year period using equal amounts of plant food.

TABLE XII. Six-year average yields of Lane farm potatoes with high and low analysis fertilizers, 1933-38.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7	239	± 5		
½ Ton 8-16-14	269	± 7	30	± 9

Both fertilizers were of regular commercial mix, and the results appear strongly in favor of the double strength or high analysis formula so far as the potato crop is concerned.

Hill and Broadcast Applications

Another point under test in the Lane farm experiment was concerned with broadcast applications and band placement of the fertilizer on both sides of the row on the level with the seed piece. The results secured indicate an increased yield for the band placement.

TABLE XIII. Effect of fertilizer placement on six-year average yields of potatoes on the Lane farm.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 broadcast	239	± 5		
1 Ton 4-8-7 in hill	256	± 8	17	± 9

While the reported increase is not statistically significant, the increases have been fairly consistent from year to year. Much work has been done on different methods of fertilizer placement by various workers, most of which has been summarized by Cummings and Houghland (11) who state that the fertilizer should be accurately placed in the soil with respect to the seed piece to be of greatest benefit to the potato crop, and that changing the position only two inches in some instances either decreased or increased yields appreciably. Practically all of the experimental work has compared different methods of placement, but has not compared placement with actual broadcasting as do the results recorded here.

From the farmer's angle, the problem is to deliver the fertilizer into the soil far enough away from the seed pieces so as not to cause burning, and still near enough so that the maximum benefit will be derived from the application. If that were always done by planter application, there would be no need for other methods. However, planter application, especially by older machines, is not always perfect; hence, there is still need for other means of application. Broadcasting is one method that can be employed, and one that is certain not to cause fertilizer burn.

Residual Fertilizer and Lime Effects

All of the fertilizer was applied to the potato crop in the rotations studied. Oats and hay have been harvested and yield-records taken to see what residual effect, if any, resulted from the use of fertilizer variables on the potato crop.

Average yields of oat-hay for the first period are given in Table XIV.

TABLE XIV. Yields of Jackson farm oats in pounds of cured hay per acre, 1928-1932.

Treatment	Yield per acre lbs.	P. E.	Diff. from check lbs. per acre	P. E.
1 Ton 4-8-7 (check)	5890	± 134		
" 0-8-7	5495	± 161	−395	± 209
" 8-8-7	6081	± 233	191	± 269
" 4-0-7	5620	± 193	−270	± 235
" 4-16-7	6250	± 261	360	± 293
" 4-8-0	5547	± 179	−343	± 224
" 4-8-3	5676	± 215	−214	± 253
" 4-8-10	6044	± 230	154	± 266
½ Ton 4-8-7	5599	± 230	−291	± 266
1½ Ton 4-8-7	6317	± 238	427	± 273
2 T. L. 1 T. 4-8-7	6214	± 233	324	± 260
4 T. L. 1 T. 4-8-7	6015	± 302	125	± 330
2 T. L. 1 T. 4-8-0	5798	± 227	− 92	± 264

While there are no differences in this table that are statistically significant, it is interesting to note that whenever an element was decreased or omitted, or a plant food was reduced, the resulting yield was lower than that of the check plots. Plots receiving an increased application of plant food or lime show an increase in yield, facts which should lend some value to the results.

Yields of hay on these same treatments are given in Table XV.

TABLE XV. Yields of hay for various fertilizer treatments on Jackson farm, 1929-33.

Treatment	Yield per acre lbs.	P. E.	Diff. from check lbs. hay	P. E.
1 Ton 4-8-7 Check	2083	± 103		
" 0-8-7	2350	± 196	267	± 221
" 8-8-7	1920	± 156	−163	± 187
" 4-0-7	1889	± 204	−194	± 229
" 4-16-7	2122	± 181	39	± 208
" 4-8-0	2165	± 172	82	± 200
" 4-8-3	2049	± 142	− 34	± 175
" 4-8-10	2424	± 231	341	± 253
½ Ton 4-8-7	2102	± 169	19	± 198
1½ Ton 4-8-7	2133	± 167	50	± 196
2 T. L. 1 T. 4-8-7	3309	± 175	1226	± 203
4 T. L. 1 T. 4-8-7	3681	± 189	1598	± 215
2 T. L. 1 T. 4-8-0	2938	± 163	855	± 193

Here again residual fertilizer effects had little influence on hay yields, the largest difference being a gain of 341 pounds in the 4-8-10 series. None of the differences for fertilizer variations are significant.

Lime gave significant gains wherever it was applied, even on the series in which potash was omitted. This was to be expected in view of the strong average acidity (pH 4.8). It is interesting to note that although the soil is responsive to lime, and that very little clover appeared on plots which did not receive lime, the increase from two to four tons gave little additional hay, actually only 372 pounds per acre as an annual average.

During the second period on the Jackson farm, lime and residual fertilizers exhibited more effect on oat yields than during the early years of the test. This fact is brought out by the two tables, XVI and XVII, which are listed.

TABLE XVI. Effect of residual fertilizer on oat yields at Jackson farm — four-year average of pounds cured oat hay per acre.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
1 Ton 4-8-7 Check	4515	± 176		
1 Ton 4-16-7	5491	± 372	976	± 412
2 Ton lime 1 T. 4-8-7	5262	± 353	747	± 394
4 Ton lime* 1 T. 4-8-7	5673	± 424	1158	± 459
2 Ton lime 1 T. 4-8-0	4779	± 327	264	± 371
1½ Ton D. S. equiv.	4803	± 386	288	± 424

*Neutralized with aluminum sulphate and sulphur.

The differences in Table XVI are all positive, which certainly indicates an effective residual effect. This appears to confirm the results obtained during the first period. Table XVI contains for the most part treatments carried through into the second period of the test, while in Table XVII oat yields are given for treatments initiated at the beginning of the second six-year period on the Jackson farm.

TABLE XVII. Yield in pounds of hay per acre of Jackson farm oats, four-year average.

Treatment	Yield in lbs.	P. E.	Gain in lbs.	P. E.
1 Ton 4-8-7 Check	3785	± 108		
" 4-8-7 500 ℔ lime	3926	± 230	141	± 254
" 4-8-7 1000 ℔ lime	4352	± 259	567	± 281
" 4-8-7 Sl.	4421	± 243	636	± 267
" 4-8-7 with Mg.	3972	± 146	187	± 182
" 4-16-14	4449	± 235	664	± 259

Yields compared with the check plot are all positive; and although the differences fail to be significant, they support previous statements as to residual fertilizer effects on Jackson farm. It seems fairly certain, therefore, that the effect of lime and residual fertilizer are carried into the oat crop; and although the differences are not large and fail of significance because of variations among plots of the same series, the effect is none the less present.

In Table XVII, two series appear which have not previously been discussed because of conflicting data in potato yields. These are plots fertilized with a 4-8-7 fertilizer, the phosphoric acid of which came from basic slag, and one which had added magnesium.

Slag gave a very slight increase in potato yields, while magnesium over the years has not shown consistent stimulating effects. While magnesium hunger has been noted on the plots treated with concentrated materials, as previously discussed, and on other farms within the area, this element does not seem to be a limiting factor on land that has been manured heavily during past years. Farms in the Colebrook area on which no manure is applied in the rotation do exhibit magnesium hunger. Farm manures used on this land prior to our lease may account for the failure of magnesium to increase yields.

Yields of hay during the second period are shown in the summaries which follow.

TABLE XVIII. Summary of Jackson farm hay yields in pounds per acre.

Treatment	Yield per acre	P. E.	Diff. from check	P. E.
		1934-39		
1 Ton 4-8-7 Check	2672	± 144		
1 Ton 4-16-7	2609	± 265	− 63	± 302
2 Ton lime 1 T. 4-8-7	4067	± 272	1395	± 308
4 Ton lime* 1 T. 4-8-7	4356	± 238	1684	± 278
2 Ton lime 1 T. 4-8-0	3397	± 226	725	± 268
1½ Ton D. S. equiv.	2485	± 235	187	± 276
		1935-39		
1 Ton 4-8-7 Check	3023	± 147		
" 4-8-7, 500 ℔ lime	2994	± 270	− 29	± 307
" 4-8-7, 1000 ℔ lime	3980	± 340	957	± 370
		1936-39		
1 Ton 4-8-7 Check	3581	± 113		
" 4-8-7 Sl.	4450	± 165	869	± 200
" 4-8-7 Mg.	3338	± 167	−243	± 202
" 4-16-14	3466	± 248	−115	± 273
" D. S. equiv.	3317	± 232	−264	± 258

*Neutralized with aluminum sulphate and sulphur.

Yields of hay were increased by liming or by the use of basic slag, except for the 500-pound lime application. Rather large increases are noted for the two- and four-ton applications, although the two-ton application on plots in which no potash was used fall considerably under the two-ton applications with normal fertilization. The 500-pound lime application apparently failed to stimulate yields comparatively, although a relatively large increase was noted for the half-ton application, as well as with the fertilizer carrying basic slag as the source of phosphoric acid.

In comparing hay yields with those of oats discussed previously, it might be said that the hay crop, because of increased clover, responded more to lime and lime-bearing substances than oats, but that the oat crop was affected more by residual fertilizer effects.

Lane Farm Oats and Clover

Not all of the oat and clover crops of the Lane farm were harvested by plots and weighed, because of poor or variable stands. For this reason no data concerning them are presented. There were no significant differences or trends in the three oat crops that were taken, nor in the two clover crops that were harvested and recorded.

Potato Measurements, Jackson Farm

During the 1936 season, measurements were taken of potatoes grown under different fertilizer treatments. In this study measurements were made of the maximum length and width of relatively large numbers of tubers to see what differences might be found. The results are expressed in the ratio of length to width in Table XIX.

TABLE XIX. Ratio of length to width of potato tubers grown on Jackson farm in 1936.

Treatment	No. tubers measured	Ratio, length to width
1 T. 4-8-7 check	479	1.305
1 T. 4-16-7	239	1.34
1 T. 4-8-14	249	1.23
1 T. 4-16-14	268	1.27
2 T. lime 1 T. 4-8-OL	640	1.435

The data show that increasing potash tends to make a shorter, blockier potato, and increasing the phosphoric acid reverses this trend. Leaving the potash out of the fertilizer accentuates the length of the tubers produced.

The Influence of a Three-Year Rotation and Fertilizer Treatments on the Organic Carbon of Soils

by W. H. Coates

THE organic carbon level of soils and its turnover are important in the growth of crops. Its level is also one of the controlling factors of accelerated erosion and soil tilth. The effects of various fertilizer treatments and a 3-year rotation are presented with general observations concerning erosion.

Thorne (26) has reviewed the research work dealing with manure and chemicals of the long-time experiments at Rothamsted, Pennsylvania, and at Ohio, Missouri, and Indiana experiment stations. The literature reviewed and the data presented by Dr. Thorne show that yields may be as successfully maintained by chemical fertilizers as by manure for ordinary farm crops. No attempt is made to disprove the value of manure. Blair (1) presents similar data showing that gains in soil nitrogen and organic carbon can be made only by losing a large amount of that which is applied.

Turk and Millar (27) concluded that nitrogen content depends on climate and cropping systems, with emphasis on biological activity and organic matter turnover. Certain crops may demand a uniform water supply which a high organic matter level helps to maintain. Lime increased organic matter decomposition, but increased the crop residues enough to balance this loss. A high correlation coefficient was found when differences in organic matter were correlated with differences in water-holding capacity. Stauffer (24) found 1.70 per cent organic carbon in plots cropped to corn; 2.20 per cent in plots cropped to corn when fertilized, and 2.90 per cent in a fertilized rotation of corn, oats, and red clover. Water-holding capacity varied from 56 per cent by weight for the soil cropped continuously to corn, to 75 per cent for the fertilized rotation.

Bushnell (8) showed that corn as green manure gave larger amounts of organic matter to plow under than either sweet clover or soybeans. Potato yields have been highest after corn. Additional nitrogen was supplied to compensate for adding large amounts of organic matter which was low in this element. Smith (22) has outlined an extensive experiment using green manure crops to increase potato yields, and has given preliminary data showing highest organic matter yields from corn and sunflowers.

Salter and Green (19) compared the effects of continuous corn, wheat, and oats, and 3-year and 5-year rotations on the nitrogen and organic carbon level in the soil. In the 3-year rotation of corn, wheat, and clover, the accumulative effect of the clover crop on the limed but otherwise untreated soil, approximately balanced the destructive effect of the corn crop. Residues of the corn crop were of little value in conserving soil nitrogen or organic carbon; those from oats were notably effective; and those from wheat intermediate in value.

Odland (18) reported that over a 40-year period, yields of potatoes have averaged about the same for five different rotations including three, four, five, and six-year rotations with legume and non-legume hays, corn, and rye. In a five-year study of continuous culture versus rotation for potatoes, Brown (5) obtained results favorable to the rotation during the two dry years of the experiment, and an index of 109 for the potatoes in the rotation as compared to 100 for potatoes continuously. Chucka and Lovejoy (9) obtained increases in potato yields when green manures and farmyard manure were utilized in addition to regular commercial fertilizers. An increase of 156 bushels resulted from the addition of one green manure crop and 20 tons of manure per acre. Other tests showed very marked yield increases from manure. These increased yields were believed due mainly to the beneficial effect of the organic matter.

Metzger (16) concluded that, in general, manure and green manure treatments maintained higher soil nitrogen and carbon levels than control plots. Commercial fertilizers tended to produce similar results, but they were much less marked.

Studies have been made on the soils of the Jackson and Lane farms to note any differences which may have occurred in organic substance. Each plot on these farms was sampled to plow-depth at the beginning of the experiments. The samples were air-dried and sealed in Mason jars. At the end of two rotations on the Lane farm and four rotations on the Jackson farm, the fields were again completely sampled and organic carbon analyses were made on all samples. All samples were pulverized to pass a 100-mesh screen and analyzed by the dry combustion method.

Experimental Data

Lane farm results:

TABLE XX. Fertilizer treatments and organic carbon in pounds per acre at the beginning and end of six-year period with odds for significance.

Treatment	1932 O. C. in lbs.	1936 O. C. in lbs.	Difference lbs.	Odds
No Fertilizer	52,600	50,600	— 2000	18-1
4-8-7 Check	52,600	50,600	— 2000	1-1
4-8-7 + L*	56,000	58,400	+ 2400	50-1
4-8-7 + LL*	54,200	55,800	+ 1600	7-1
4-16-7	51,000	49,400	— 1600	2-1
4-0-7	55,200	50,800	— 4400	33-1
8-8-7	51,800	51,600	200	1-1
0-8-7	51,400	50,000	— 1400	>100-1
4-8-0	48,400	47,200	— 1200	3-1
4-8-14	52,000	49,400	— 2600	4-1
4-8-7 in bands	54,600	50,800	— 3800	>100-1
8-16-14 (1000 lbs.)	53,600	51,600	— 2000	10-1
4-8-7 No Mg.	56,400	54,000	— 2400	>100-1

*L equals [illegible]00 lbs. ground limestone, LL equals 1000 lbs.

Jackson farm results:

TABLE XXI. Fertilizer treatments and organic carbon in pounds per acre at the beginning and end of 12-year period, with odds for significance.

Treatment	1927	1939	Difference	Odds
4-8-7 Check	75,000	65,600	− 9400	>100-1
4-8-7 (3,000 lbs.)	79,600	68,000	− 11600	↓
4-8-10, 6 yrs. / 4-8-14, 6 yrs.	74,800	65,000	− 9800	↓
4-16-7	69,600	66,600	− 3000	↓
4-8-0 + L*	72,600	65,200	− 7400	↓
4-8-7 + L*	72,000	66,600	− 5400	

*L in this table equals 2 T. ground limestone.

TABLE XXII. Fertilizer treatments and per cent and average yearly increase or decrease in organic carbon.

Treatment	Per Cent Increase or Decrease in O. C.	Yearly Average
Lane farm — 6 years		
No Fertilizer	−3.80	−0.63
4-8-7 Check	−3.80	−0.63
4-8-7 + L	+4.29	+0.72
4-8-7 + LL	+2.95	+0.49
4-16-7	−3.14	−0.52
4-0-7	−7.99	−1.33
8-8-7	−0.39	−0.06
0-8-7	−2.73	−0.46
4-8-0	−2.48	−0.41
4-8-14	−5.00	−0.33
4-8-7 in bands	−6.96	−1.16
8-16-14 (1000 lbs.)	−3.73	−0.62
4-8-7 No Mg.	−4.56	−0.76
Jackson farm — 12 years		
4-8-7 Check	−12.5	−1.04
4-8-7 (3000 lbs.)	−14.6	−1.22
4-8-10 — 6 yrs. / 4-8-14 — 6 yrs.	−13.1	−1.09
4-16-7	− 4.3	−0.36
4-8-0 + L	−10.2	−0.85
4-8-7 + L	−10.3	−0.86

Discussion of Results

The losses of organic carbon from the check plots on the Lane farm were not statistically significant. However, several other treatments of similar nature gave significant or nearly significant results for similar decreases. These included the one-half ton 8-16-14 application and the 4-8-7 no magnesium application. Little, if any, benefit was derived from the magnesium in crop yields. These three treatments gave total losses of 2000, 2100, and 2400 pounds of organic carbon per acre for the six year period. These values represent losses of 0.63, 0.62, and 0.76 per cent per year.

The organic carbon losses were great when the fertilizer was applied in bands in the row. No particular reason was evident from the yield data to account for this large loss.

The fertilizer applications plus lime and double lime show additions to the organic matter level.

In order of increasing phosphorus applications, the data show a decreasing loss of carbon. Organic carbon losses increased when applications of potassium were increased although the results obtained were not statistically significant. Applications of 4-8-7 fertilizer resulted in higher losses than either the 0-8-7 or the 8-8-7.

Accelerated soil erosion had become noticeable in the area. This erosion was in the form of sheet removal with the formation of very small rills on some sections of the field.

Results on the Jackson farm gave approximately the same losses for the 4-8-7 check, 4-8-7 (3000 pounds per acre), and the 4-8-10=4-8-14 combination. Organic carbon losses were materially decreased with the high phosphorus application. It should be noted that the organic carbon levels in the plots having this treatment were lowest at the beginning of the experiment in 1927. The organic carbon level in 1939 in these plots was not as low as was found in some other treatments. Benefits which amounted to reductions from 22 to 42 per cent in organic carbon loss were obtained from the use of lime.

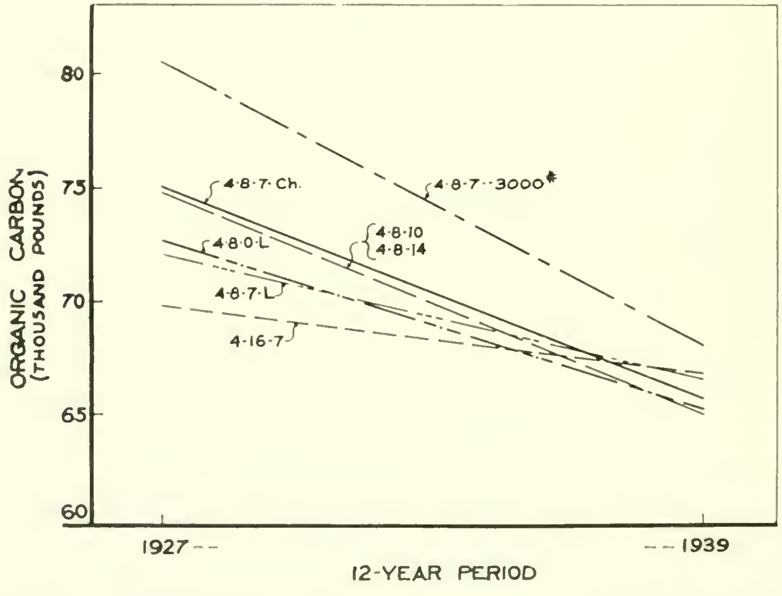

Figure 1. Organic carbon in pounds per acre at beginning and end of 12-year period, Jackson farm.

Figure 1 shows the tendency of the organic carbon level to approach a value caused by the effect of climate and the given cropping system.

The difference between the highest organic carbon level and the lowest at the end of the experiment, represented the range of possible changes which may be effected by varying the fertilizers. This statement assumes the experiment has been carried on sufficiently long to level out original existing differences in organic carbon levels. This difference of 3000 pounds of organic carbon might be particularly important on some soils, particularly if accelerated erosion was impending. Since this difference of 3000 pounds of organic carbon is much less than original differences, it is concluded that the combined effects of the rotation and cultivation were greater than those exerted by the various fertilizers. The crop response is conditioned by the organic carbon level. A given treatment applied to an area of high humus content may show a reduction in organic carbon level, whereas the same treatment applied to a similar area of low humus may have a beneficial effect.

Potato Scab Control

Attempts have been made to reduce potato scab on certain Jackson plots which were heavily limed, and on limed plots on Whenal and Ireland farms, Greenland, by the use of aluminum sulphate and sulphur.

Considerable data have been accumulated on this phase of the work. While certain trends are indicated, such as the increase in acidity due to their use, and some reduction in scab, the results are not wholly consistent, due probably to the complex factors involved.

The scab organism is the most widely distributed of any potato disease. Many workers have noted that this organism increases in destructive action between pH 5.5 and 7.0, but decreases above or below these points. Blodgett and Howe (2) noted in a study of potatoes on 313 farms in New York that the least scab occurred in soils with pH 4.3-5.4, more scab on soils with pH 7.5-8.5, and the most scab on soils ranging from pH 5.45-7.4. This work was later confirmed in general by Smith (22) in an experiment in which soil acidity was controlled in pH by lime or sulphuric acid.

In the studies reported here, none of the soils were limed to the neutral point, although because of imperfect spreading and mixing, there doubtless were localized areas of soils with four-ton lime applications which reached that point. For this reason most of the lime applications used doubtlessly placed the soil within the optimum range for scab development.

Data covering Whenal farm potatoes in 1935 and 1936 are reported in Table XXIII, and Jackson farm in 1936 and 1937 in Tables XXIV, XXV, and XXVI. These tables cover the soil pH, and scab counts. For convenience in listing, notations for scab cover bad, medium, and slight or no scab; and the figures given are percentages of the total number of tubers counted. Bad scab is defined as being severe enough to throw the tuber out of grade so that it would have to be sold on its merits as a scabby potato. Medium scab is defined as being severe enough to be noticeable, and if only a few such potatoes were present, they might be retained in the number one grade, while those only slightly scabby would under any condition go into the number one grade.

TABLE XXIII. Whenal farm scab counts, 1935-1936.

	pH			1935 Scab			1936 Scab			
Treatment	Spring 1935	Fall 1935	Fall 1936	Bad	Slight	None	Bad	Medium	Slight	None
600 lbs. $Al_2(SO_4)_3$	6.09	4.58	4.59	2.4	7.3	90.4		.49	2.54	96.97
600 lbs. sulfur	5.98	4.03	4.67	4.8	15.6	79.5	2.87	3.22	11.37	82.54
400 lbs. $Al_2(SO_4)_3$	5.75	5.30	5.06	9.8	21.9	66.3	3.67	12.49	22.19	61.64
200 lbs. $Al_2(SO_4)_3$	5.84	4.65	4.49	7.0	10.9	82.1		.21	2.50	97.29
200 lbs. sulfur	5.39	5.03	5.07	21.3	33.6	45.1	11.15	12.17	11.41	65.27
No treatment	5.48	5.52	5.09	17.9	21.8	60.3	17.88	19.14	23.52	39.44

3 plots average for each group; 7 no treatment plots. Same land in potatoes 1935 and 1936. Field laid out in plots, in three strips of 8 plots each. One strip limed 4 tons per acre in 1925, 1 strip limed 2 tons per acre in 1925, and the other limed 2 tons per acre in 1931. Each acidulating treatment crosses these 3 strips, 1 plot wide.

TABLE XXIV. Jackson farm potato scab counts, 1936.

Treatment	Plot	pH Spring	pH Fall	Bad	Medium	Slight	None
300 lbs. $Al_2(SO_4)_3$	90W	5.97	5.3	74.75	21.0	4.04	.21
	115W	(	5.9	100.00			
	115W	(5.74	5.39	79.02	16.4	4.59	
	68W	5.5	5.74	99.0	1.0		
900 lbs. $Al_2(SO_4)_3$	90E	5.72	5.21	33.57	35.06	18.60	12.78
	115E	(	5.88	100.00			
	115E	(5.90	5.25	42.61	25.80	24.35	7.24
	68E	5.5	5.36	87.95	6.02	6.02	

TABLE XXV. Jackson farm potato scab counts, 1936.

Treatment	pH Spring	pH Fall	Bad	Medium	Slight	None	Acidulated with
LLN E	5.68	5.36	66.03	16.72	12.24	5.01	900 lbs. $Al_2(SO_4)_3$
LLN W	5.70	5.52	88.19	9.60	2.16	.05	300 lbs. $Al_2(SO_4)_3$
L		5.06	9.20	18.19	32.75	39.83	Nothing
4-8-0 L		5.17	1.52	9.35	28.35	60.78	"
1000 L	4.85	4.79	3.68	9.55	14.92	71.85	"
500 L	4.54	4.61	3.97	3.01	9.55	83.47	"
Slag		5.11	10.17	11.97	26.61	51.25	"

TABLE XXVI. Jackson farm potato scab counts, 1937

Treatment	pH	Bad	Medium	Slight	None	Acidulated with
LLN E	5.12	62.1	20.6	15.3	2.0	900 lbs. $Al_2(SO_4)_3$
LLN W	5.36	71.8	19.8	6.6	1.8	300 lbs. $Al_2(SO_4)_3$
L	5.14	54.9	23.5	19.2	2.4	Nothing
4-8-0 L	5.19	22.7	27.3	37.5	12.5	"
4-8-7 Slag	5.31	11.5	18.5	31.5	38.5	"
1000 L	4.78	1.2	3.8	23.5	71.5	"
500 L	4.68	.2	1.1	7.9	90.9	"
Check	4.74	.6	3.8	17.3	78.3	"

LL equals 4 T limestone applied 8 years previously.
L equals 2 T limestone applied 8 years previously.
1000 L equals $\frac{1}{2}$ T limestone applied 2 years previously.
500 L equals $\frac{1}{4}$ T limestone applied 2 years previously.
Slag—slag used instead of superphosphate in making a 4-8-7 fertilizer.
4-8-0—fertilizer without potash.

A higher degree of consistency is shown in Table XXIII, Whenal farm data, than in Table XXIV. Both acidulating substances reduced the pH value of the soil and tended to reduce the amount of potato scab. In the main, aluminum sulphate appears to have had more effect than sulphur in reducing scab, as judged by the percentage of potatoes in both years that were entirely free from scab. It is impossible to correlate these results definitely with pH values, so it is not clear whether the variations in scab amounts are entirely due to the substances used or to soil conditions over which no control was exercised.

Table XXIV lists scab counts on three plots which had been limed at the rate of four tons per acre eight years prior to the potato crop of 1936. Before the potatoes were planted in 1936, the plots were divided and one end treated with 900 pounds, the other with 300 pounds of aluminum sulphate per acre.

The results do not appear very consistent, mainly because of plot 115 which exhibited different conditions on either side of the plot, whereas in our acidulating work the plot was divided crosswise. One side of the plot exhibited 100 per cent bad scab regardless of treatment. The soil was not sampled in the spring to cover this variation, but the sampling at digging time showed a much higher pH value on that side of the plot on which the bad scab occurred than on the other. Aside from this factor, pH values were lower on all tests after treatment than before, and the heavy application reduced the amount of scab to an appreciable extent more than the light one.

In Tables XXV and XXVI scab counts are presented from plots on Jackson farm which had previously been limed or had received lime-bearing substance in the fertilizer. It will be noted in Table XXVI that check plot counts in 1937 showed only 78.3 per cent of tubers free from scab although very little bad scab was present. Potatoes from plots treated with basic slag showed considerably more scab infection than those treated with 500 or 1,000 pounds of lime, whereas the most scab appeared on the heavily limed plots even though that lime had been applied eight years before the data were taken, and were acidulated in addition.

From the data it is apparent that land can be acidulated and scab injury reduced by the application of aluminum sulphate or sulphur, although in no instance was perfect scab control obtained. In fact, it seemed that the costs of acidulating soils by the use of one of these substances was too great to warrant their use in actual farming practice; and from the growers' point of view it would be preferable to plow under green manure crops, or use a broadcast application of sulphate of ammonia to achieve the results desired.

Cooking Quality of Potatoes

by Paul T. Blood and Ford S. Prince

DURING the course of the rotation studies and fertilizer trials with potatoes on Jackson and Lane farms, it seemed desirable to determine the quality of the potatoes produced under various fertilizer treatments. Early tests made in the years of these experiments consisted in cooking the potatoes and then having different individuals rate them by taste. This method proved unsatisfactory because of variable individual preferences, and also because of the impossibility of tasting a large number of potatoes within a given sample so as to cover the variations within that particular lot.

Accordingly, a rapid method of estimation of potato quality was devised so large numbers could be tested. This method consisted in determining the specific gravity of individual tubers grown under different conditions. Facilities for making these rapid tests were first set up in New Hampshire by Paul T. Blood, assistant agronomist, and the results of the first tests were reported by Haddock (14), February 10, 1938, on potatoes grown in 1937. Later reports by Haddock and Blood (4) reviewed some of the literature on potato mealiness and cooking quality, and described in detail the method employed. "Eleven salt solutions of varying specific gravities ranging from 1.055, 1.060 . . . to 1.105 were prepared. A 'definite' number of tubers were selected from the potato sample to be

Method used in specific gravity test for potato quality.

tested and were immersed in one of the solutions, preferably starting with the solution in which the bulk of the tubers would barely float. Floaters were then transferred to the solution of lower specific gravity and sinkers to solutions of higher specific gravity. Tubers are classified as having the same specific gravity as the solution in which they barely float."

The Relation Between Specific Weight and Starch Content of Potato*

In view of the relationship between the specific gravity and potato quality, it seemed desirable to review the literature dealing with specific gravity and starch content to see whether it would be possible to speak of specific gravity, quality, and starch content in one breath.

German starch factories have used the specific gravity of potatoes for many years to calculate the amount of starch in the wagon loads brought in to the factory, and payment for the potatoes has been based upon such determinations. Von Scheele, Svensson & Rasmusson (28) (1937), cite the work of seven European workers who, as a result of chemical analyses, published tables showing the relationship between starch content and specific gravity to be a straight line. Von Scheele and co-workers recalculated the relationship using a more accurate method for the determination of starch, and they have compared their results with those of the other workers. Von Scheele and co-workers used 540 samples of two kilos each, covering several varieties and several soil types over a period of four years. They found a correlation coefficient of +0.947 in the relationship between specific gravity and per cent of starch, and showed that with the help of a calculated straight line, the specific weight could be used as an accurate index for the percentage of starch present. The few values that fell off the line were off by not more than one or two per cent.

The following equation was given as the regression line expressing the relationship between starch content and specific gravity.

$$Y = 17.564 + 199.07\ (X - 1.09879)$$

where Y = Starch content X = Specific gravity

An admirable review of the literature of starch chemistry up to 1928 has been made by Walton (30) (1928). The references which he cites indicate that European workers have known of the close correlation between starch content and specific gravity for years. The most common method for the determination of the specific gravity of potatoes appeared to be based upon the well-known Archimedes' principle whereby the tubers are first weighed in water and then in air. This same method evidently is now used in the German starch factories (c.f. Von Scheele).

However, several investigators suggested the use of several salt solutions with different specific gravity. The tubers either float or sink in the solutions, and the specific gravity of the solution in which the tuber neither floats nor sinks is also the specific gravity of the tuber. Schultze (20) (1871) placed a number of potatoes in a concentrated solution of sodium chloride and diluted the solution until one-half of the potatoes sank to the

*The authors are indebted to W. H. Lyford, Jr., of the New Hampshire Experiment Station for the review of the literature of relationships between potato starch and specific gravity and for the starch determination presented in Table XXVII.

bottom, while Fresenius (13) (1881) reported a method of adding water or salt solution until the specific gravity of tuber and solution was the same, subsequently determining the specific gravity of the solution by a hydrometer.

American workers also have investigated the relationship between starch content and specific gravity, and have shown the close correlation which exists between these two, notably Winton (31) (1887); Cutler (12) (1891); Watson (30) (1895); Shutt (21) 1926).

However, both the European and the American workers have pointed out that while the correlation is close to one, it is not exactly one, and on that account a determination of the specific gravity may not always give the correct value for starch even though it does in the majority of determinations. Because of this fact, chemical methods are still considered most reliable even though they are tedious.

The recent work at this station by Blood and Haddock, and that of Clark, Lombard, and Whiteman (10) (1940), has shown that the relationship between the specific gravity of potatoes and their quality as judged by mealiness is very close. In view of the fact that starch content and specific gravity are also closely correlated, it would appear logical to state that quality is usually dependent on the starch content.

Because of the apparent relationship between starch content and quality as determined by specific gravity, it becomes interesting to know whether Von Scheele's table may be used for estimating the starch content of our American varieties in order that we may relate starch content and quality if desired. A check of this was made by analyzing several Green Mountain tubers of known specific gravity for their starch content. Specific gravity was determined by the use of salt solutions, and starch content was determined by the use of the autoclave method described by Von Scheele. Individual tubers were used for the analysis, and were grated by hand on a common kitchen grater. The pulp was very thoroughly mixed before transferring into covered weighing bottles, and from this point on, the autoclave method was used without modification. A preliminary check with pure potato starch had shown that the method was accurate. The results of these few analyses are shown below in table form.

TABLE XXVII. Comparison of the starch content of several individual Green Mountain potatoes with that presented by Von Scheele.

Specific weight	Per cent starch in Green Mountain potatoes	Per cent starch obtained by Von Scheele - page 75
1.120	21.9	21.8
1.120	22.1	21.8
1.115	19.0	20.8
1.103	17.9	18.4
1.097	16.5	17.2
1.084	13.8	14.6
1.062	10.2	10.2
1.061	9.1	10.0 (calculated)
1.054	6.7	8.6 (calculated)

The results presented in this table show that Von Scheele's regression line is applicable to our American varieties, provided the per cent of starch is not needed within one or two per cent. As Von Scheele ex-

TABLE XXVIII. Potato quality as shown by specific gravity test (Jackson farm)

Fert. treatment (1 Ton broadcast)	No. tubers used	Poor		Fair		Good		Excellent			Quality rating	pH
		1.065	1.070	1.075	1.080	1.085	1.090	1.095	1.100	1.105		
4-8-7	400		1	1	4	14	17	36	20	7	93.4	4.69
4-8-14	300	3	8	19	28	28	9	3	2		80.95	4.69
4-16-7	300		1	1	3	9	17	33	28	8	94.55	4.66
4-16-14	300	3	7	8	29	26	16	8	2	1	83.9	4.66
4-8-7 Slag*	300	1	1	5	16	27	25	20	4	1	87.4	5.26
4-8-7 + 20lb boron	200			1	4	14	26	32	20	3	92.8	4.62
667lb 12-24-22**	200			2	1	12	18	34	24	9	94.45	4.88
1000lb 12-24-22**	300			2	10	23	27	22	14	2	90.25	4.76

*P_2O_5 supplied from basic slag rather than from superphoshate.

**Made up with equal amounts of Ammo Phos A and nitrate of potash.

TABLE XXIX. Potato quality as shown by specific gravity test (Lane farm).

Fert. treatment (1 Ton broadcast)	No. tubers used	Poor		Fair		Good		Excellent			Quality rating	pH
		1.065	1.070	1.075	1.080	1.085	1.090	1.095	1.100	1.105		
4-8-7	100		10	9	8	39	22	9	3		84.65	5.06
4-8-14	100	19	11	19	20	20	9	2			77.3	5.02
4-16-7	100		5	8	15	27	18	17	9	1	86.85	5.08
4-8-0	100				4	16	24	34	17	5	92.95	5.10
4-0-7	100	1		3	6	28	31	19	12		89.45	4.96
0-8-7	100	3		15	20	31	10	8	6		83.05	5.11
8-8-7	100		7	10	22	36	20	5			83.35	4.83
No fertilizer	100		1	2	2	15	20	27	27	6	93.50	5.21

presses it: "Since at the extreme 96-97% of the samples lie within 1.5% of the regression line, it may be assumed that the starch content of single samples may be obtained with an error of ±1.5% by means of the determination of the specific gravity."

While this review and data indicate that specific gravity is not infallible as a means of characterizing the starch content, yet, it does indicate that in a large majority of instances the starch content and specific gravity may be used interchangeably.

Tests on Quality of Potatoes by Specific Gravity

After the preliminary tests on potatoes grown in 1937, and reported by Haddock (14), larger samples were used in 1938 because it was found that there was considerable variation even in the same sample of potatoes, provided enough tubers were used. The data for 1938 reported by Blood and Haddock (3) are presented.

In Tables XXVIII and XXIX the quality rating given is the average specific gravity of the entire sample tested, with the first digits of the specific gravity omitted. For example, if the average specific gravity of a sample is 1.095, the rating is given as 95. In this way relative quality ratings are noted, and denote the exact average specific gravity itself.

It will be observed in Table XXVIII, Jackson farm potatoes, that in the 1938 crop potatoes from the high phosphorus treatment have the highest rating. These are closely followed by the plots receiving one-ton equivalent of a high analysis fertilizer (12-24-22) made up from equal parts of Ammo Phos "A", 11-48-0, and nitrate of potash, 13-0-44. It will also be observed that the check plot potatoes (4-8-7) stand third in this list. Potatoes from plots with high potash fertilizer, 4-8-14 rated 80.95 as against 93.4 for the check treatment, while those which received extra phosphorus and potash both, tested 83.9, slightly higher than the potatoes treated with a high potassium fertilizer.

Potatoes which were produced on plots treated with a 4-8-7 fertilizer in which the phosphoric acid was derived from basic slag rated 87.4 as compared with 93.4 for the check plots. Yields were not materially increased under slag treatment, but the pH of the soil was increased significantly and more scab developed here than appeared to be warranted by the pH change produced by this alkaline phosphorus carrier. Boron changed the appearance of the potatoes by imparting an external luster, but did not have an appreciable effect on cooking quailty.

Table XXIX gives similar results for Lane farm plots on potatoes produced in 1938. These data support those of Table XXVIII, since tubers produced with high phosphorus exhibit a higher quality rating, and those with high potash have a lower rating than the check plots. Increasing or omitting the nitrogen appeared to have little effect on quality, but omitting the phosphoric acid or potash, or omitting the fertilizer entirely seemed to have a beneficial effect on quality, although, of course, the yields under these treatments were seriously reduced and the potatoes were much smaller than those from plots more favorably treated.

Table XXX presents a summary of quality ratings of potatoes from comparably fertilized plots from Jackson and Lane farms for the 1938 season.

TABLE XXX. Comparison of potato quality as influenced by climatic conditions.

No.	Fertilizer treatment 1 Ton per acre broadcast	Location	Quality rating
1	4-8-7	Colebrook	93.4
2	4-8-7	Chichester	84.65
3	4-8-14	Colebrook	80.95
4	4-8-14	Chichester	77.3
5	4-16-7	Colebrook	94.55
6	4-16-7	Chichester	86.85

This table appears to show that the more favorable potato climate in the Colebrook area is conducive to the production of potatoes of higher starch value and better cooking quality. While this was true of the 1938 season, we have reason to believe that such results might not always be secured, and that in other seasons in which climatic conditions in central or southern New Hampshire were more favorable for high yields, the reverse of these results might be expected.

In support of this contention, Table XXXI is presented giving the quality ratings of potatoes picked at random from fields of members of the 300 bushel potato club in 1939.

TABLE XXXI. Quality ratings of potatoes from 300 Bushel Club members, 1939.

Sample	No. tested	Poor	Fair	Good	Excellent	Yield per acre	Quality rating
		below 1.070	1.075-1.080	1.085-1.090	1.095-1.110		
1	50	1	1	5	43	418	101.7
2	70			13	57	355	99.3
3	45		2	11	32	325	98.4
4	65		3	14	48	498	97.1
5	49		1	13	35	515	96.5
6	50			12	38	321	96.1
7	119	5	10	25	79	520	94.3
8	75	1	5	34	35	374	92.3
9	50		6	22	22	411	91.1
10	60	1	2	38	19	350	90.6

The potatoes in this table are all of the Green Mountain variety and represent fields from northern New Hampshire as well as other sections of the state. Growers represented by sample Nos. 5, 6, 7, and 10 are from Coos county, the most northern county in the state, while those of Nos. 1, 4, and 9 are from Cheshire, a county in extreme southwestern New Hampshire. Of the other three, two are from Grafton, bordering Coos county on the south, and one from Belknap county in central New Hampshire. It will thus be seen that of ten growers having potatoes of the highest quality ratings in 1939, the first four were outside of Coos county, and three of the growers including those in first and fourth place were in the southernmost county of the state.

Further data on quality ratings of potatoes produced on Jackson farm in 1939 are shown in Table XXXII. The Chippewa variety was produced here in 1939, and this fact may account for seeming discrepancies of data when compared with Tables XXVIII and XXIX. Subsequent data

TABLE XXXII. Quality ratings, Jackson farm potatoes, 1939, Chippewa variety.

Fertilizer treatment	No. tubers tested	Average quality rating
1 T. 4-8-7 Check	300	83.6
1 T. 4-8-14	300	78.6
1 T. 4-16-7	200	79.1
1 T. 4-16-14	200	77.4

will confirm the fact that the Chippewa has, on the average, a much lower quality rating than Green Mountain. Furthermore, according to our tests it is more sensitive to fertilizer variations than the Green Mountain, and especially so to different phosphoric acid levels. The quality rating ascribed to the 4-8-7 treatment is unusually high for Chippewa, while quality ratings for the three variables are very close together, and all below that of the check treatment.

Blood and Haddock (4) have noted variations in quality ratings of potato varieties grown on Jackson and Lane farms in 1938. For the sake of brevity, certain tables are condensed and included here to direct attention to the differences that actually occur among varieties grown with similar treatment but under different climatic conditions.

TABLE XXXIII. Quality ratings of potato varieties, 1938 crop.

Variety	No. of tubers	Quality rating Jackson farm	Quality rating Lane farm
Green Mountain	100	94	82
Smooth Rural	100	89	75
Russet Rural	100	84	81
Irish Cobbler	100	83	73
Warba	100	81	71
Chippewa	100	79	65
White Rose	100	71	60

In every case the potatoes grown on Jackson farm have a higher quality rating than those on Lane farm, the differences ranging from three points in the Russet Rural to fourteen in the Smooth Rural variety. This difference, as we have previously pointed out, would probably not hold in every season, but it happens to do so in 1938.

In respect to the varieties themselves, the Green Mountain has the highest rating in both instances and the White Rose the lowest. With the exception of the Russet and Smooth Rural varieties on Lane farm, the tests show a descending quality rating as arranged in Table XXXIII.

Further evidence on the quality ratings of Green Mountain and Chippewa varieties accumulated from tests made on the 1939 crop produced by 28 three hundred bushel club members from all New Hampshire counties. Quality ratings of Green Mountains tested vary from 78.0 to 101.7, while Chippewa ratings vary from 62.7 to 77.6. It is interesting to note that the highest quality Chippewa is on the same level with the lowest quality Green Mountain.

Another factor that doubtless plays a part in determining the quality rating is date of planting, although this would be associated with the climatic factor. In a test in 1939 on Whenal and Ireland farms, Greenland, New Hampshire, potatoes planted on different dates were later tested for quality. The variety used in this test was Green Mountain, planted on

TABLE XXXIV. Quality tests of potatoes planted at different dates, 1939, Greenland, N. H.

Date of planting	Date of harvest	No. tubers tested	Quality rating
May 12	October 15	200	82.2
June 5	October 15	350	89.0
July 1	October 15	270	92.1
July 1	September 15	10	81.5

similar land and fertilized in exactly the same way. The season was very dry and potatoes planted May 12 suffered materially from drouth, yielding only about one-third as much as those which were planted June 5, while those which were planted June 5 outyielded those planted July 1. Potatoes from May 12 planting showed much "second growth"; those planted June 5 exhibited some second growth, but the July 1 planting was free from this condition.

Quality ratings of potatoes from the various plantings dug October 15 show a higher figure for the July 1 planting, which was the planting that suffered least from adverse weather conditions, while those planted May 12 have the lowest rating. A few potatoes dug September 15 from the lot planted July 1 exhibit a quality rating about ten points lower than those which were left in the ground and allowed to approach maturity undisturbed. These data seem to show that any factor which may delay growth in midseason may influence starch formation to such an extent that later amendments cannot be made, and that maturity is doubtless a factor of some importance in determining quality ratings or starch formation.

With respect to second growth, some "dumb-bell" shape tubers were divided at the line of constriction and subjected to these tests. The seed end of such potatoes proved to have a much higher specific gravity than the stem end. Of samples tested this difference amounted to about 30 points in the quality rating, or about 85 for the seed end, 55 for the stem end, and 70 for the potato as a whole.

The evidence is fairly convincing that there are inherent differences in quality ratings among varieties, as well as variations due to climatic factors, date of planting, and maturity; and while there is some ground for the belief that certain fertilizers may contribute to variations in potato quality, the fundamental causes underlying the wide variations that have been encountered within a variety still await adequate explanation. From reference to Tables XXVIII and XXIX for example, which give the distribution of the potatoes of the samples tested under the various specific gravities, wide variation within each samples is apparent. Tests of potatoes from the same hill indicate that these variations are to be found there as well and while a given hill or sample may have a high average quality rating, individual tubers within the group may have a relatively low rating. Whether this is due to a difference in time of setting of the tubers, the ability of one potato in the hill to secure a more adequate food supply than another, or whether the position of the potato in the soil with regard to depth that might influence the temperature and the proper assimilation of food materials, has not yet been determined.

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Summary

FERTILIZER studies with potatoes reported in this bulletin have been conducted by producing potatoes with a 4-8-7 fertilizer, one ton per acre, and comparing with this standard treatment a fertilizer in which each of the elements was omitted, reduced or increased with the other two elements constant.

Evidence obtained warrants the conclusion that in omitting an element, potash causes the greatest reduction in yield, with phosphoric acid second and nitrogen third. This was true both for the Jackson farm lying at a high elevation in northern New Hampshire, and for Lane farm lying at a lower elevation in south central New Hampshire.

Phosphoric acid caused a greater increase in yield than either of the others when this element was doubled on the Jackson farm, with potash and nitrogen ranking in that order, while on Lane, stimulation from extra phosphoric acid and potash were nearly equal, nitrogen again ranking last.

Tests during the second six-year period on Jackson farm ascribe considerably more stimulation to a fertilizer with a high phosphorus level than with high potash, with however, a significant increase for a fertilizer in which phosphoric acid and potash were both doubled.

Need for Phosphorus

Because of the apparent need for more phosphoric acid than is found in the normal potato fertilizer, especially on land at higher elevations or northern latitudes and since there is already a tendency toward higher potassium formulæ, it seems that it will often be advantageous to increase both elements from the 1-2-2 or 2-4-5 to a 2-5-5, or perhaps a 1-3-3 ratio at least.

Evidence is presented indicating that the potato variety may have an influence upon the choice of the fertilizer ratio, some varieties being more sensitive to phosphoric acid variations than others. In the main, the tests reported were with the Green Mountain, a variety that is less sensitive than either the White Triumph or Chippewa, although these varieties were grown but one year each.

Different levels of fertilizer of 4-8-7 grade on Jackson farm gave an increase of 68 bushels for a ton over the one-half ton application, and a further increase of 45 bushels for another half ton in addition to the ton amount. The increase for the additional one-half ton in the latter case was approximately equal to that for extra phosphorus in the 4-16-7 formula. In the Lane test one ton of fertilizer increased the actual yield 69 bushels per acre over no fertilizer, although the average size of the potatoes produced with no fertilizer was so small that this procedure is not to be recommended.

The use of lime in conjunction with a fertilizer carrying no potash had a depressing effect upon yields, indicating that lime ties up potash that would otherwise be available to the potato crop.

Double-strength fertilizer caused a significant increase in yield over single strength on Lane farm, when equal amounts of plant food were used. On the Lane farm banding the fertilizer along the sides of the row gave a slight increase over broadcasting the fertilizer.

Magnesium did not affect yields appreciably in either test.

A limited amount of data with boron on Jackson farm does not seem to warrant the use of this element at present on a soil with the history of that of the Jackson farm field.

Other Crops in Rotation

In these tests a three-year rotation of potatoes, oats, and mixed hay was practiced on Jackson farm with a rotation of potatoes, oats, and clover on Lane farm. In both rotations all the fertilizer was applied to the potato crop. Yields of oat hay on Jackson farm follow fertilizer treatments, the omission of an element causing a decrease, and the increase of an element resulting in an increased yield. Liming affected oat yields favorably. Hay yields were influenced very slightly by residual fertilizers but more markedly influenced by liming. Data on oats and clover from Lane farm are not included due to variable stands on different sections of the field.

Data on potato measurements show a tendency toward a shorter, blockier potato for those grown under high potash, while high phosphorus reverses this trend, a trend which is accentuated by omitting the potash altogether.

Lime on Potatoes

On both Jackson and Lane farms the use of lime had very little effect on potato yields. Fertilizers which left a strong residual acid reaction on Jackson farm, however, failed to perform well in increasing or maintaining yields, and the potato foliage exhibited symptoms typical of magnesium hunger which would indicate that this soil is now or may soon be at the critical point for soil acidity.

Data from an experiment on Ireland farm, Greenland, show an increase in potato yields on limed plots when the previous crop was utilized as green manure.

The influence of lime on potato scab is noted as well as the use of acidulating substances to increase acidity and reduce scab effects. Of the acidulating substances used, equal amounts of aluminum sulphate were slightly more effective than sulphur in reducing scab and changing the soil reaction. The use of these substances to change soil reaction and reduce potato scab should scarcely be considered under farming conditions, but it is felt that plowing under green manures or applying sulphate of ammonia broadcast as a source of a part or all of the nitrogen in the potato fertilizer would result in more economy to the potato grower as a remedy for overliming.

Organic Matter

The three-year rotations practiced on both Jackson and Lane farms, without organic manures, failed to maintain the organic matter level which existed at the beginning of the trials. Jackson farm plots which received a high phosphorus treatment showed least loss in organic carbon, while the omission of phosphorus from Lane farm resulted in a loss of organic carbon more than double that from the high phosphorus treatment. In view of the importance of soil organic matter in increasing infiltration and preventing erosion, and because of accelerated erosion on many potato farms of the state, this phase of the work demands and will receive further study.

Liming had a favorable effect on the organic carbon level, actually increasing it on Lane and showing less decrease than certain other treatments on Jackson farm.

Because of the favorable effect of lime on the maintenance of organic matter and in view of scab dangers from its use, it seems logical to conclude that lime should be used only in guarded amounts of 500, or not more than 1000 pounds per acre on soils that have reached or are below pH 5.0 in reaction. An accurate soil test along with the behavior of clover and other crops grown in rotation should always be used as a guide before lime is applied to the soil in a potato rotation.

Specific Gravity Test for Potato Quality

Literature covering the relationship between the specific gravity of potatoes and their starch content is reviewed. It shows that starch content may be determined to within one or two per cent by determining the specific gravity of the tubers in question. This is substantiated by actual starch determinations of potatoes having a known specific gravity.

Since the starch content of a potato is definitely associated with mealiness, it is concluded that the method of rapidly determining the specific gravity of potatoes by immersing them in salt solutions of different strengths may be used as a means of arriving at an estimation of potato quality.

From the tests which have been made and reported it seems apparent that fertilizers have a slight effect upon potato quality, high phosphorus tending to increase and high potash tending to decrease quality ratings. These tests show also that there are wide inherent differences in quality ratings among varieties, some varieties ranking high and others uniformly low. Date of planting, the maturity of the tubers at harvest, and climatic factors all play their part in affecting the quality ratings of potatoes within a variety. Potatoes that are well matured before harvest, and especially those which have been grown without any setbacks in midseason due to adverse weather exhibit high quality. Variations in quality ratings of potatoes grown in the same hill are as yet unexplained.

Because of varietal differences noted it is felt that breeding may in the future play a large part in increasing quality ratings. At the present time, the wisest course for the farmer seems to point to using a well-balanced fertilizer designed to promote maturity, and to plant his crop at a time when it is least likely to be affected by midsummer drouth or heat. A controlled water supply would undoubtedly help in this respect. A study of the causes of differences in quality that exist among potatoes in the same hill may or may not throw further light on methods of procedure whereby the average quality rating will be increased.