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THE EFFECTS OF NITRATES ON THE COMPOSITION OF THE POTATO

By WILLIAM P. HEADDEN

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THE EFFECTS OF NITRATES ON THE COMPOSITION OF THE POTATO

By WILLIAM P. HEADDEN

A few years ago Colorado potato growers suffered heavy losses due to attacks of diseases. The difficulty appeared, according to C. L. Fitch, suddenly in 1911, continued during the years of 1911-'12-'13 and '14, and disappeared in 1915. The difficulty was spoken of in a general way as the Leaf Roll. My information is that several causes contributed to these unfortunate results.

The only part that the Chemical Section of the Station took in the investigation at that time was to visit the Greeley district and take a number of soil samples and determine the ratio of nitrate nitrogen to the total. This ranged up to 17 percent, whereas 5 percent is a high ratio under ordinary conditions, especially in soils occupied by growing crops.

We have nothing to do with the theories advanced to account for the trouble, but one of these attributed it directly to temperature and moisture of the soil. This is broad enough, and rich enough in indirect results, to cover a great many difficulties.

EXPLANATIONS OFFERED, NOT WHOLLY SATISFACTORY

The writer was convinced that a nearer approach to the cause would be made by studying the supply of plant food and the effect of the ratios of the different elements on the structure and composition of the plants. So far as I could learn, no new factor had been introduced into our conditions. The chief agents causing the trouble were considered to be *Altenaria*, *Fusarium* and *Rhizoctonia*, but these we have with us at all times, and it seemed to me then that there was some reason why these organisms should suddenly become so violently pathogenic, especially the *Fusarium*, to which I understood the greater part of the trouble was attributed. This violently pathogenic characteristic of the fungus was evidently acquired and persisted through those years. The organisms were present prior to this time and are with us still, but it was only for four years, in fact for a less time, that they were so harmful. It is the same organism all the time, capable under proper conditions of becoming very harmful. My idea was that one of the conditions was a condition of the plant, that, on the one hand offered less resistance, and on the other hand, furnished a better medium for the development of the fungus than usual. If the cell walls were thinner or weaker than usual and the juices of the plant richer in nitrogenous compounds, such as asparagine for instance, the fungus might develop vigorously enough to occupy the whole stem of the plant with its mycelia.

The food elements on which we lay the greatest stress are phosphorus, potassium and nitrogen, the latter of which is almost wholly appropriated in the form of nitrates. An abundant, not to say excessive, supply of these promotes the vegetative processes, indicated, in most cases clearly, by the size and color of the leaves. In the case of wheat we have weak stems that knee and lodge badly and are clearly very susceptible to the attack of the rust fungus peculiar to the plant. I thought that a similar series of related facts might hold for the potato. If there be such, the conditions under which they become apparent are far less simple than in the case of the wheat plant. In the wheat plant we have three very pronounced effects shown by the application of nitrates; 1st, a darker leaf accompanied by weak straw; 2nd, a very pronounced susceptibility to rust; 3rd, a marked difference in the appearance and composition of the fruit. In the case of the sugar beet, we have an excessive foliage and a depression in the quality of the beet. I do not know whether any definite observations have been instituted to ascertain whether beets grown with an excessive supply of nitrates are more susceptible to the diseases that affect the plants or not. In all of the experiments that I made, we sprayed heavily in anticipation of such attacks.

EFFECTS OF NITRATES NOT SO PRONOUNCED ON GROWTH OF POTATOES AS ON WHEAT AND SUGAR BEETS

In the cultivation of potatoes at Greeley, Colorado, there was but little, if any, difference in the color and growth of the plants that received 800 pounds of sodic nitrate to the acre and of those that received none. There are two evident conclusions to be drawn; First, that the potato plant is not so sensitive to the supply of nitrates at its disposal as are the wheat and sugar beet plants; Second, that the natural supply in the soil is sufficient to produce an almost maximum effect on the growth of the vines. I am confident that both of these conclusions are partially applicable. One would be justified in asserting that there was no difference in the growth and color of the plants, but it certainly was not marked, as it always is in the case of wheat or of sugar beets. The growth of oats in the adjoining land, as well as data to be given subsequently, indicate an abundant supply of nitrates during the growing season. We demonstrated that the composition of the wheat plant and its fruit are both very materially affected by the relative supply of nitric nitrogen, and that these effects were not produced by other forms of nitrogen, such as occur in farmyard manure nor by water; and for the sugar beet we demonstrated that an excess of nitrates produced very undesirable results. First, they affected the growth of the beet delaying maturation; they affected the quality of the beet increasing the injurious nitrogen and injurious ash and depressed the sugar content. The juices of these beets do not work well in the factory for several reasons; first, because they are the juices of green beets; second, because of the presence of injurious forms of nitrogen and of ash constituents which interfere with the crystallization of the sugar, or to express it otherwise, they are molassegenic factors. Again, the nitrates affected the shape of the beets causing them to grow sharply top-shaped, producing a high percentage of crown and a yield of topped beet disproportionate to that indicated by the growth of the tops. The development of the potato is entirely different from that of these crops, still the fundamental requirements of the plants are essentially the same so far as plant food is concerned, and we supposed that an undue supply of nitrogen would, in this case as in the others, produce definite characteristics in the composition and structure of the plant that would help in explaining the experiences had by potato-growers in the Greeley and other districts of Colorado in the years given, 1911 to 1914 inclusive.

TEMPERATURE, DRAINAGE AND SOIL-ATMOSPHERE

The factors of temperature and water supply cannot be left out of consideration. How important a part these factors may play in this question the writer does not know, nor has he found anything in the literature accessible to him that is, in any measure, satisfactory. That the potato produces well and that the produce is usually of good quality in mountainous sections might be taken to indicate that the temperature and drainage of these sections were determining factors in the case, and that the soil had less to do with it. This may be so, but the diseases that we have to complain of are present in our high valleys. San Luis Valley, with an altitude of 7,500 feet, has been as sorely afflicted as Greeley. In these cases the climates are very different. I do not know the maximum temperatures nor their duration at these places, but the San Luis Valley may have frost every month in the year. Their nights are cool. Their soil is, for the most part, well adapted to the culture of potatoes and yet there are portions of this valley in which, I am informed, the potato crop is more often a failure than a success; in other portions of the valley this crop is usually dependable and profitable, and it certainly would lead us into very great perplexities if we should attempt to discuss the relations of water to these problems.

The relation of temperature and moisture to the problems involved in the culture of the potato involve the biological activities of the soil, and these in turn involve the character of the soil atmosphere. These factors are to me of unknown potentialities, but we must assume that they are factors of some importance and it is evident that temperature and moisture are of very great importance in this respect.

It is scarcely surprising that we have not ascertained the conditions which determine the outbreak of diseases, as in 1911 in the Greeley district, or those under which the disease or diseases persist in certain sections.

OBJECT STATED—RESULTS NOT CONCLUSIVE

The object had in view in undertaking the experiments recorded in this bulletin was to study the composition and characteristics of our potatoes, and more especially to find out what, and how great an influence an excessive supply of nitrates may have upon the growth, composition and health of the plant, i. e. whether it rendered it more susceptible and less resistant to disease than other plants. In the latter respect our results are, to say the very best of them, inconclusive. No one has suffered from disease during the period of our experiment as they did in 1911-'14, and our potatoes have been much like everybody else's. At the present writing it remains to be seen whether the keeping qualities of the tubers produced under the different conditions are equally good. The crop of 1920 did not show any difference that was noted, but the crop of 1921 gives indications of differences so marked that a satisfactory interpretation may be made to the effect that the tubers produced on the plots having received an application of 800 pounds of sodic nitrate per acre are inferior in this respect to those from plots that received no application of nitrates.

The pathological features of these experiments lie beyond my province and it is not my intention to go beyond the general statements already made. I shall confine myself to the study of the chemical composition of the soil, the plants and tubers produced. I have had nothing to do with the cultivation of the plots beyond advising the amounts of nitrates to be applied. The cultivation was, however, standard for the Greeley district and thorough, so that no degree of failure whatsoever is to be attributed to mistakes in cultural methods or to indifferent execution. The experiments were seriously interfered with in 1920 by a severe hail storm which beat down, cut and bruised the vines so badly that we made no study of them. But we did carry through the whole series of samples of tubers, except that we made no cooking experiments, which, for the purposes had in view in this work, is not of such direct importance as the composition and other properties of the tubers. We shall, however, in a subsequent bulletin, record this feature for the crop of 1921 because it has a popular interest, is a recognized property of the tubers, and completes a little more fully our investigation of the subject. These cooking qualities give us another measure of the value for the potatoes.

CULTURAL METHODS NOT DISCUSSED

The cultural method prevalent in the Greeley district is that of "high hilling." This means that the plants stand in a ridge so high above the bottom of the irrigating furrow between the ridges that the irrigating water is applied below the point where the tubers are formed, and reaches them by capillary rise through the soil. In this way the tubers develop in a well-drained and well-aerated soil. These conditions should be borne in mind in connection with the soil samples taken during the growing season, as these were taken close to the plants, and from the middle of the top of these ridges. It will be recognized that in this work we are not concerned with the discussion of methods of cultivation; our potatoes were cultivated in this manner, and our soil samples represent these conditions. Discussion of the methods of cultivation is given in almost every bulletin published on the subject of potato growing.

THE SOIL

The soil is classified as Fort Collins loam. It is somewhat clayey and cannot be considered as a real good potato soil. The subsoil varies somewhat within the area used in these experiments. The soil, as this term is understood, is about twelve inches deep and is not very different from the subsoil, which, however, is a little heavier and occasionally contains segregations of carbonate of calcium; sometimes they are mixed with, or may be largely composed of sulfate of calcium.

We shall present in the following pages the mechanical, mass and agricultural analyses of samples of this soil. The agricultural analyses have been made using two methods of extraction, concentrated hydrochloric acid and fifth normal nitric acid. These analyses are given in order that those who wish to study the features involved in the total supply of plant food may have as complete a statement of the case as we can give from which they can make their own deductions. We cannot, unfortunately, present the biological characteristics of these soils except in so far as the fixation and nitrifying efficiency of these samples may be a measure of, perhaps, the most important of these biological features. We hold these to be of the utmost importance, not only in connection with the diseases which wrought such damage in the years of failure but at all times in the nutrition and growth of the plants. I believe them to be more worthy of study than the purely chemical factors to which, in the main, we must confine ourselves. That the relations between these factors are intimate is certainly beyond question. The difficulties in establishing what these relations may be are probably great, but they will be established, and we shall someday know how intimate and important these relations are.

We shall take up no space with description of methods of investigation, as we have followed well-beaten paths. If, at any point, we have deviated, we shall make definite statements to this effect.

We have made mechanical and mass analyses of the soils only, as we see no gain in making these analyses of the subsoils.

MECHANICAL ANALYSES OF THE GREELEY SOILS

	Percent
Over 1 mm.	0.160
1 mm. to 0.5 mm.	1.431
0.5 to 0.25 mm.	1.723
0.25 to 0.05 mm.	54.752
0.05 to 0.01	20.057
0.01 to dust	15.206
Fire clay	2.530
Ignition	4.141
	100.000

MASS ANALYSES OF THE GREELEY SOILS

Laboratory number	2618	2622	2624	2630	2632
	Percent	Percent	Percent	Percent	Percent
Moisture at 115°	2.189	2.050	1.753	1.800	1.762
Ignition	3.075	4.070	3.195	2.880	3.200
SiO_2	77.100	75.580	76.210	77.540	77.080
TiO_2	0.481	0.480	0.496	0.290	0.505
SO_3	tr	tr	0.135	0.170	0.024
CO_2	tr	tr	tr	none	tr
Cl	0.087	tr	tr	tr	tr
P_2O_5	0.124	0.080	0.135	0.110	0.125
Al_2O_5	8.759	8.650	0.925	8.420	8.059
Fe_2O_3	3.304	3.610	3.200	3.360	3.260
Me_3O_4	0.150	0.220	0.047	0.110	0.045
CaO	1.180	1.500	1.250	0.960	1.400
MgO	0.724	1.040	1.086	0.860	0.968
K_2O	2.184	2.040	2.622	2.440	2.572
Na_2O	1.004	1.040	1.305	1.220	1.049
CuO	tr	....	....	....	....
As_2O_3	tr	....	....	....	....
Li_2O	None				
Sum	100.361	100.36	100.459	100.160	100.045
O = Cl	0.021				
	100.340	100.36	100.459	100.160	100.045
Total nitrogen.	0.0832	0.0950	0.0891	0.0790	0.0850

The excess in the following analyses, an excess of nearly two percent, is much too great, but the determination made on the solutions were repeated in many instances and no considerable errors were found, and I do not think the excesses in the summation of sufficient importance to justify a repetition of the whole analysis, so I give the analyses as obtained. The soluble silicic acid in the statement of an agricultural analysis of a soil may be of importance as being a measure of the silicates present in the soil capable of entering readily into the reactions that may be going on in it. But in any attempt to discuss these reactions of which we are still in doubt, it can make but little difference whether the soluble silicic acid be given as 14.9 or 15.4, which is approximately the difference that would fall upon the soluble solicic acid if the excess were distributed. I have preferred to state the results just as the analyst reported and I accepted them.

AGRICULTURAL ANALYSES OF GREELEY SOILS*

Laboratory number	2618	2620	2622	2624	2630	2632
	Percent	Percent	Percent	Percent	Percent	Percent
Moisture at 115°	1.650	2.226	2.974	2.179	2.118	2.175
Ignition	3.056	3.789	3.829	3.360	3.357	3.012
Insoluble	72.646	71.394	69.651	75.080	76.553	78.425
Soluble SiO_2	14.814	13.092	13.566	11.862	10.908	9.346
SO_3	0.072	0.051	0.054	0.062	0.031	0.034
CO_2	0.200	0.425	0.564	0.100	0.058	0.196
Cl	0.262	0.796	0.188	0.077	0.275	0.289
P_2O_5	0.096	0.127	0.061	0.096	0.061	0.057
Al_2O_3	0.334	3.543	4.505	3.474	2.504	3.168
Fe_2O_3	3.930	3.440	2.910	2.680	2.765	2.650
Mn_3O_4	0.520	0.250	0.240	0.230	0.215	0.380
CaO	0.660	1.075	1.295	0.690	0.545	0.610
MgO	0.876	0.902	1.035	0.734	0.650	0.463
K_2O	0.771	0.639	0.466	0.645	0.510	0.421
Na_2O	0.386	0.214	0.326	0.542	0.230	0.166
Sum	100.273	101.963	101.674	101.811	100.780	101.392
O equivalent to Cl	0.059	0.180	0.042	0.017	0.062	0.065
Total	100.214	101.783	101.632	101.794	100.718	101.327

*Digestion with HCl sp.g.1.181 or concentrated acid for 10 hours (nominally).

AGRICULTURAL ANALYSES OF THE GREELEY SUBSOILS*

Laboratory number	2619	2621	2623	2625	2631	2633
	Percent	Percent	Percent	Percent	Percent	Percent
Moisture at 115°	1.966	3.600	3.340	3.110	3.621	1.873
Ignition	2.983	3.624	3.817	3.287	4.008	2.943
Insoluble	66.793	65.419	66.641	70.766	65.764	73.003
Soluble SiO_2	17.503	14.998	14.890	13.819	14.913	11.879
SO_3	0.041	0.078	0.075	0.045	0.031	0.017
CO_2	0.150	1.239	0.057	0.040	0.000	0.100
Cl	0.247	0.265	0.213	0.186	0.215	0.76
P_2O_5	0.153	0.143	0.098	0.127	0.071	0.074
Al_2O_3	2.477	2.164	5.300	4.830	5.649	3.826
Fe_2O_3	4.550	3.563	4.105	3.030	3.380	3.480
Mn_3O_4	0.630	0.240	0.280	0.240	0.300	0.430
CaO	0.650	2.270	0.643	0.555	0.505	0.500
MgO	1.083	1.107	1.065	0.845	0.947	0.880
K_2O	0.587	0.628	0.876	0.535	0.735	0.556
Na_2O	0.440	0.401	0.214	0.534	0.507	0.376
Sum	100.253	101.749	101.714	101.949	100.646	100.113
O equivalent to Cl	0.056	0.060	0.048	0.042	0.049	0.040
Total	100.197	101.689	101.666	101.907	100.597	100.073

*Solvent concentrated hydrochloric acid.

These subsoils were taken from the 13th to the 24th inch, both inclusive and represent the second foot of this land. There are differences in composition, but so far as one would venture to judge from these analyses, these subsoils are quite as good as the soils when properly aerated. The differences in the amounts of organic matter must be approximately the same as the differences in the loss on ignition, which are very small. The total ignition is low, showing that in these soils the sum of organic matter and water retained at 115 degrees amounts to rather less than four percent. In only one instance does the sum of these two amount to this much. This is rather surprising, as this land had been in alfalfa which was broken up only a little while before these samples were taken.

EFFECTS OF ALFALFA NOT APPARENT

The whole soil was taken but the larger alfalfa roots, of course, were rejected. We would expect the surface foot to be enriched in organic matter to a greater extent than we find it. The amount of leaves and small stems lost in making alfalfa hay is very considerable, amounting to about 20 percent of the total dry matter produced by the crop of alfalfa. By this is meant that if 4 tons of hay were actually gathered from an acre of this land in 1919, there had been produced 5 tons of dry matter, one ton of which had been left in the land and was equivalent to the application of 70 pounds of nitrogen and 170 pounds of ash constituents. The rotation followed in this case calls for two years in alfalfa. The land had received approximately twice these quantities, together with the plants themselves, but the differences shown by the analyses give no hint of these facts. One would, it is true, scarcely expect to find results due to the direct additions made, because they are too small when figured in percentages, but we would be justified in this case in expecting a gross accumulation of organic matter at least pronounced enough to be detected. These analyses do not show any such desirable effects of the alfalfa. We shall, however, have further opportunity to learn of conditions in these soils; in the meantime, it is not to be inferred that we doubt the benefits of the rotation, but we are a little surprised that the beneficial effects do not appear to be reflected in appreciable measure in the analytical results. The digestion with concentrated hydrochloric acid is, beyond doubt, rather drastic if we expect to draw conclusions from the results regarding the actual amounts of food supply available to the plants at the time the samples were taken. The method, however, certainly gives us maximum limits for these amounts, and in a measure gives us the immediately potential resources of the soil. In this view and in this view only, we have considered it advisable to present such analyses of the soil. For the purpose of obtaining a better view of the more immediately available resources of this soil, we avail ourselves of the fifth normal nitric acid extract.

The analyses of the subsoils are given in the same order as those of the soils, so that the analysis of the subsoil falls under the corresponding soil to which it belongs; laboratory number 2619 falls under 2618 with which it pairs. Of course intervening text is neglected.

As the moisture, ignition, carbon dioxid and chlorin determinations were made on the general samples, they are common to the two sets of analyses.

AGRICULTURAL ANALYSES OF GREELEY SOILS*

Laboratory number	2618	2620	2622	2624	2630	2632
	Percent	Percent	Percent	Percent	Percent	Percent
Moisture at 115°	1.650	2.226	2.974	2.179	2.118	2.175
Ignition	3.065	3.789	3.839	3.360	3.357	3.012
Insoluble	92.200	90.790	89.930	91.459	92.110	91.910
Soluble SiO_2	1.700	1.610	1.660	2.101	1.980	2.140
SO_3	0.010	0.010	0.010	0.017	0.017	0.027
CO_2	0.200	0.425	0.564	0.100	0.058	0.196
Cl	0.262	0.796	0.188	0.077	0.275	0.289
P_2O_5	0.058	0.077	0.058	0.058	0.077	0.070
Al_2O_3	0.289	0.038	0.176	0.334	0.239	0.263
Fe_2O_3	0.210	0.330	0.290	0.270	0.290	0.290
Mn_2O_4	0.230	0.300	0.210	0.260	0.230	0.280
CaO	0.500	0.920	1.040	0.560	0.420	0.500
MgO	0.195	0.261	0.279	0.253	0.232	0.232
K_2O	0.200	0.161	0.211	0.137	0.112	0.118
Na_2O	0.010	0.021	0.016	0.075	0.042	0.053
Sum	100.770	101.528	101.445	101.030	100.834	101.492
O equivalent to Cl	0.059	0.197	0.043	0.018	0.062	0.065
Total	100.711	101.331	101.402	101.012	100.772	101.427

*Extraction with n/5 nitric acid.

AGRICULTURAL ANALYSES OF GREELEY SUBSOILS**

Laboratory number	2619	2621	2623	2625	2631	2633
	Percent	Percent	Percent	Percent	Percent	Percent
Moisture	1.966	3.600	3.440	3.110	3.621	1.873
Ignition	2.983	3.634	3.817	3.287	4.008	2.943
Insoluble	91.470	87.820	90.550	91.779	89.197	91.990
Soluble SiO_2	1.490	1.530	1.490	1.611	1.480	1.620
CO_2	0.150	1.239	0.057	0.040	0.000	0.100
Cl	0.247	0.265	0.213	0.186	0.215	0.176
P_2O_5	0.064	0.083	0.051	0.051	0.064	0.083
Al_2O_3	0.100	0.272	0.138	0.251	0.175	0.313
Fe_2O_3	0.310	0.330	0.310	0.260	0.440	0.270
Mn_2O_4	0.260	0.270	0.250	0.250	0.220	0.220
CaO	0.500	1.980	0.510	0.440	0.420	0.400
MgO	0.232	0.377	0.275	0.235	0.250	0.256
K_2O	0.244	0.165	0.215	0.103	0.124	0.114
Na_2O	0.026	0.037	0.042	0.047	0.064	0.064
Sum	100.059	100.615	101.320	101.670	100.208	100.439
O equivalent to Cl	0.055	0.059	0.048	0.042	0.048	0.039
Total	100.004	100.556	101.272	101.628	100.160	100.400

**Extraction with n/5 nitric acid.

SUPPLY OF POTASH AND PHOSPHORIC ACID ABUNDANT

Personally I am not convinced that an attempt to interpret the results of these analyses will serve any good purpose. The big features are so plain that anyone interested enough to read them can see that even with the weaker solvent, fifth normal nitric acid, an abundance of phosphoric acid and potash goes into solution to meet the requirements of many more crops than this, and several generations can grow on these lands. The amount more or less readily available, i. e. soluble in fifth normal nitric acid would suffice to grow 115 crops of 200 bushels of potatoes to the acre, and the amount soluble in hydrochloric acid would meet the requirements of the 200 bushel crop of potatoes for 170 years more, and beyond this lies a much larger supply especially of potash. These statements assume that the surface soil to the depth of one foot alone supplies the phosphoric acid and potash requirements of the potato crop which is by no means the case, for the roots of the potato plant penetrate freely to a depth of two feet and often to a depth of four feet. The extraction of the soil by concentrated hydrochloric acid probably gives very nearly the whole of the phosphoric acid present in the soil but by no means the whole of its reserve in potash, as the felspars are only very slowly attacked by this agent and even the phosphoric acid extraction is not complete.

The soluble silicic acid, which is abundantly present, probably should be interpreted as showing a relatively large amount of easily decomposed silicates consisting of silicates of alumina with lime, potash and soda and also containing water. Such silicates are very reactive and our soils ought to respond quickly and favorably to the application of such fertilizers as may be needed. The fact that the application of commercial fertilizers has heretofore failed to give the hoped for results is accounted for by the considerations presented in this connection.

NO ATTEMPT MADE TO ACCOUNT FOR SMALL YIELD

It might be thought that I should go further in this direction and attempt to explain why the yields obtained in this district are not two or three times as large as they are. This I cannot do. Perhaps they should be two or three times as large as they are. The plant food is in the soil in abundance, but there are other factors operative in the case that limit the crops to their present volume and influence the quality as well. I have already stated, rather plainly I think, that the object had in view in undertaking this work was not to study cultural methods or results but to study a single feature, almost exclusively, as possibly the determining cause for the failures of the past. The work done in the prosecution of this study has had this one object in view. Much fundamental work has been done because the desired facts had not previously been acquired and put on record. We had no intention of going into a study of the ratios existing between the quantities of plant food supplied by the soils, nor of experimenting to solve such problems. So far as I know this presents a class of problems never undertaken for our soils; I know that experiments have been made with artificial fertilizers, but the results have been disappointing. It may be that the preceding paragraphs offer the explanation and perhaps they do not. My personal conviction is that the suggestions relative to the supply of phosphoric acid and potash, the inorganic elements universally considered of primary importance, are not satisfactory and adequate to the explanation of the facts.

WATER-SOLUBLE PORTION OF OUR SOIL NOT VERY IMPORTANT

The water-soluble portion of our soils is usually large, much larger than that of eastern and European soils in which this plant is grown. I do not know whether this is a factor in our questions or not. I presume that it is, but what part it plays I do not know. Abundant yields are obtained in lands heavily impregnated with our ordinary alkalies and also in lands free from them from which it would follow that sodium, calcium and magnesium salts are not important factors in the problems presented. These are, so far as my knowledge goes, unexamined phases of the problem. These may be important phases but our observations in different parts of the state do not lead us to consider them as promising subjects for investigation. If my impressions in this matter be entirely at fault, it still remains very clear that the chief difficulties in potato-growing complained of are not involved in these features, for these are all constant factors; I may say, universal and permanent factors in our questions, whereas the difficulties mostly complained of are variable in the extreme. I have already cited a case in which the same land produces a good crop once in four or five years and failures the other three or four years. The plant foods and their ratios are probably just as abundant and favorable, and the alkalies no more abundant during the three or four unfavorable years than during the good one.

NO GENERAL SOLUTION OF THE PROBLEM PROBABLE

These things unite in showing that the problems are complex to such an extent that a solution of them all at one time or the finding of one general cause is not at all probable. The best that one is justified in hoping for is a series of partial solutions which may at times not be in harmony with one another and need much adjustment to one another to make them seem at all reasonable. The problem presented in this bulletin is: What are the effects of nitrates in the soil upon the growth, composition and properties of the potato plant and tubers? Under properties in connection with this problem, we consider the susceptibility to disease more important than the usually considered cooking qualities, though these, too, will be included later. We assume that the spores of the various fungi to which our destructive diseases are due are sufficiently abundant to infect a sufficient number of potatoes, especially if bruised, to demonstrate the susceptibility of the crop as shown by the keeping quality of the tubers. If there are twice as many tubers, grown with nitrates, that show infection with fungi as there are affected tubers of the same variety grown in the same plot of land but without the application of nitrates, we conclude that the nitrate added has increased the susceptibility of the tubers to the attacks of these fungi, be they what they may.

POTATOES CONSIDERED IN THIS BULLETIN

In the succeeding pages of this bulletin we shall address ourselves to the composition and qualities of Colorado-grown tubers in general,—the composition and qualities of tubers grown in the Greeley district with and without the application of nitrates, and the composition of the vines grown with and without nitrates. The pathological features lie beyond our province except in the most general way.

No study of the potatoes peculiar to the Greeley district has been made. Only potatoes grown on our own experimental plots have been examined or will be discussed. In this statement "our own experimental plots" means on the plots of the Colorado Potato Experiment Station. It may be well in this connection to state that Dr. H. G. MacMillan of the Bureau of Plant Industry, U. S. Department of Agriculture, pathologist at the Potato Experiment Station, with whom it has been a pleasure to be associated in this work, is in no measure whatsoever responsible for the statements made in this bulletin. Any errors contained herein are mine and not his. At the same time I am glad to acknowledge my obligations to him for willingly given information, advice and words of encouragement. He has, however, no responsibility for either the statements of facts or the conclusions set forth in this bulletin.

NITROGEN IN THIS SOIL

In the statements of the analyses of the soils heretofore made, the question of nitrogen has not been mentioned, because I propose to address myself to this subject almost to the exclusion of the other factors. The total nitrogen shown in the analyses is below the average for good soils. One reason for laying stress upon the nitrogen content of the soil is evident from the statement of the purpose that we had in view. We surmised that these soils furnished enough nitrogen during the growing season to constitute an excessive supply for the potato plant and render it less resistant than normal to the attack of disease, and that in the years of severe attacks the amount furnished had been sufficient to be very deleterious when occurring in conjunction with other conditions tending to produce the same results. In other words, the effects of the nitrates upon the growth of the plant render the cell walls weaker and the juices richer in nitrogen, making the latter a better medium for the sustenance of the fungi, and the cells less able to resist their attacks. With these considerations in view, we attempted to follow the development of the nitrates in the soil during the season.

This land had been in alfalfa for two years and the stubble with a growth of at least four inches had been plowed under only a short time previous to the taking of the samples. We had in the surface foot of soil the accumulated effect of the two years in alfalfa with that of the crop plowed under. The roots were still green and were not taken with the sample. The samples were air-dried which, according to determinations made, means from 1.9 to 3.0 percent of moisture in the soil.

INCUBATION TESTS

The first question that we tried to establish in regard to the relation between this soil and nitrogen content was its ability to fix and nitrify nitrogen. The original content of total nitrogen and nitrate nitrogen is given in the following table.

The moisture content of the soil was made up to 15-17 percent with ammonia-free water and incubated for periods of 30 and 40 days, when the nitrogen determinations were repeated. No source of energy was added to these. The experiments imitated field conditions as nearly as possible in a small way.

The supply of energy that the soil flora found in the dishes would have been available to it in the field. It may be stated, however, that all of the soils that we have tested develop a luxuriant growth of algae; of course this growth is mixed. The following incubation tests were made with the samples whose analyses have been given, and were made immediately after the samples were taken 20 March, 1920:

INCUBATION EXPERIMENTS WITH THE SOILS

LABORATORY NO.	At the Beginning		After 30 Days		After 40 Days	
	Total Nitrogen	Nitric Nitrogen	Total Nitrogen	Nitric Nitrogen	Total Nitrogen	Nitric Nitrogen
2618, surface 12-in....	0.0832	0.00116	0.08687	0.00321	0.0851	0.00400
2619, subsoil 12-in....	0.0668	0.00111	0.07050	0.00315	0.0720	0.00270
2620, surface 12-in....	0.0863	0.00258	0.09125	0.00292	0.0900	0.00360
2621, subsoil 12-in....	0.0801	0.00160	0.08700	0.00222	0.0813	0.00275
2622, surface 12-in....	0.0950	0.00198	0.10720	0.00263	0.1003	0.00302
2623, subsoil 12-in....	0.0650	0.00116	0.07666	0.00321	0.0771	0.00295
2624, surface 12-in....	0.0891	0.00140	0.09350	0.00303	0.0935	0.00395
2625, subsoil 12-in....	0.0689	0.00140	0.08900	0.00268	0.0721	0.00302
2630, surface 12-in....	0.0790	0.00163			0.0905	0.00412
2631, subsoil 12-in....	0.0632	0.00140			0.0715	0.00327
2632, surface 13-in....	0.0850	0.00081			0.0862	0.00387
2633, subsoil 12-in....	0.0567	0.00215			0.0645	0.00275

As the result of the changes going on in these samples, we find at the end of 40 days an increase in the total nitrogen ranging from 12 to rather more than 100 p. p. m., or from 75 to 625 pounds of proteid matter per million of soil. This increase in total nitrogen is shown by the subsoils as well as by the soils. One of the subsoils gives an increase, calculated as proteid matter, of 750 pounds per million. This sample was taken 12 inches deep, i. e. a layer of subsoil 12 inches thick and approximately 12 inches square was taken out, mixed on a canvas and sampled, so that the results obtained show the fixing power of that subsoil taken one foot deep. Under the conditions of our incubation chamber, which differed from those in the soil probably in aeration and moisture and certainly in temperature, an acre-foot of this subsoil is capable of producing 2600 pounds of proteid matter in 40 days. Such facts remove the assertion that this soil and subsoil possess a fixing power for the atmospheric nitrogen from a general statement and establish it as a definite fact and give us a fair measure of its amount which varies, but is of sufficient magnitude to leave no doubt about its actuality as a factor.

The amount of nitric nitrogen ordinarily present in good soils, not occupied by growing crops, is about 8 p. p. m. We observe that while the total nitrogen in this soil is scarcely up to the average quantity present in good soils, which may be taken at one-tenth of one percent, which is generally considered the lowest adequate limit for the nitrogen supply, the nitric nitrogen is materially above the maximum usually present, even as much as three times this amount. It is to be remembered that these samples were taken 12 and 15 inches deep and represent the soil and subsoil and not the surface inch or two of the soil in which much larger amounts of nitric nitrogen may be found. No such surface samples of this soil have been examined. These samples representing the plots on which we grew our potatoes were more than ordinarily rich in nitric nitrogen to begin with, which would justify the inference that their nitrifying power was more than an average one; the incubation tests show that every sample, whether of soil or subsoil, made an increase varying from one and a half time to over four times the amount present at the beginning. The prevailing gain was between two and three times the amount originally present. These properties are not mentioned as peculiar to Greeley soils, for we know them to be common to most of our soils, but they are present in a large measure in these soils on which we made our experiments.

Some of the plots that we planted to potatoes abutted upon land planted to oats which at this time, 20 May, indicated by the color and size of the leaves that their supply of nitrogen was abundant. We took four samples from this oat plot for the determination of the nitric nitrogen. We found in the samples taken to a depth of 3 inches, 19.9 and 13.4 p.p.m. of nitric nitrogen, and in those taken from 4 to 6 inches we found 18.6 and 13.2 p. p. m. The oats grew rankly and lodged. They had at this date the equivalent of 223 pounds of sodic nitrate available in the top 6 inches of the soil. The first sample in each pair was taken from the north end, and the second from the south end of the field which was probably 1000 feet long.

NITRATES FORMED IN THE SOIL

Since the potatoes were cultivated by the "high hilling" method, the ridge in which the potato vines stand receives no water directly from the irrigating ditch, but is moistened from the sides by capillarity. The surface is not puddled or baked but is mellow to a depth of several inches. This condition allows of excellent aeration and together with the moisture is favorable to both the increase of the total nitrogen by fixation and to its nitrification. On the other hand, the occupancy of the ground by the rootlets of the plant may tend to inhibit both of these processes. The presence and growth of the plant on the one hand tends to inhibit, and on the other to use up the nitric nitrogen or nitrates formed. The nitric nitrogen found in soils occupied by growing plants is what is left of that which is formed under adverse conditions. We appreciated these relations and assumed both series of facts to be operative, still we took samples of this soil from the center of these ridges and close to the plants; in taking the later samples it was quite common to cut into a tuber. The samples were taken with a soil tube to a depth of 3 to 4 inches, 20 subsamples were united to form a composite sample, a plug was taken every 15 feet alternately from the two central rows of the plot. Six series of samples were taken during the season. We should have had a fallow plot treated in the same manner as the planted area but we did not foresee the advisability of this at the beginning. We later attempted to correct this omission but the plot was not satisfactory as the conditions were not comparable.

It is understood that no samples were taken from land to which we had applied nitrates, only from the check plots. There were four rows in each check plot and we took our samples from the two middle rows only, using the two outside rows as guard rows.

NITRIC NITROGEN IN P.P.M. IN THE HIGH CROWNED ROWS OF POTATOES

Plot Number	7 July	26 July	6 Aug.	9 Aug.	2 Sept.	16 Sept.
1 west	27.3	65.0	69.2	70.2	187.0	33.0
2 west	27.8	49.5	68.0	85.5	34.0	38.0
3 west	26.5	42.1	66.0	52.3	40.0	39.0
4 west	24.3	40.6	65.0	80.7	47.8	39.5
5 west	21.0	47.0	82.0	79.5	46.0	41.0
6 west	25.7	46.7	60.7	79.5	63.5	30.6
7 west	28.2	74.0	51.3	50.8	60.6	28.8
8 west	26.8	70.2	37.8	47.5	42.8	25.5
9 west	27.3	45.2	60.2	53.0	49.0	38.8
1 east	20.2	59.7	72.0	54.0	54.5	40.8
2 east	21.0	43.4	48.0	56.5	36.8	46.5
3 east	22.0	53.5	91.0	59.0	42.5	37.5
4 east	20.5	58.7	56.0	49.0	39.0	25.2
5 east	21.3	66.0	56.7	33.0	12.3	13.3
6 east	22.0	59.2	40.5	54.0	29.7	16.8

The samples of this soil taken in May are not comparable in any way to these for they were taken to a depth of one foot shortly after having been plowed to a depth of 9 inches, whereas these samples were taken to a depth of 3 to 4 inches only, after six weeks or thereabouts of alternate rest and cultivation. I cannot state whether it had been irrigated in the meantime or not, but I think not. We see that the nitric nitrogen is already high in early July and increases until 9 August, but then falls almost to the level of early July except that the southern part of our samples, 1, 2, 3, 4 and 5, west plot, fell slowly after September 1.

Moisture determinations were not made in these samples at the time of taking, but they probably contained from 13 to 15 percent including the dry surface soil that was taken with the sample. At times the samples taken may have carried more than 15 percent moisture, but the average was not far from this figure.

SOIL CONDITIONS UNDER WHICH OUR EXPERIMENTS WERE MADE

The conditions of the soil, so far as the questions under consideration are involved, were, at the beginning of our experiments as follows: mechanically, it was rather heavy for our purposes, it is in the lower part of the field, but is only fairly well drained. An alfalfa sod had just been broken up, our water supply was sufficient for irrigating it; the supply of potash and phosphoric acid soluble in fifth normal nitric acid was adequate for the production of many crops; the total nitrogen in the soil is low; the surface soil, taken to a depth of 12 inches, of our west plot averaged 0.0884 percent and that of east plot taken to about the same depth averaged 0.0820 percent. The subsoil in the west plot, taken 12 inches deep, average 0.0704 and in the east plot 0.06 percent. The humus was not determined, but it is evidently present in very moderate quantities even in the very surface portions of the soil.

These percentages of nitrogen found in the soil at the beginning of our experiments are from one-tenth to one-fifth below the generally assumed adequate lower limit of nitrogen for the production of good crops. The nitric nitrogen present in the top foot of this soil is from one and a half to three times as great as the maximum usually found in good soils, while the subsoils have nearly the same average. The nitric nitrogen in the surface soil on 20 May was 11.0 percent of the total, whereas about 5.0 percent is usually the maximum ratio found under ordinary conditions.

SOIL SHOWS STRONG FIXING POWER

As the results of incubation tests we find that the surface soils fix from 37 to 121 p.p.m. of nitrogen in 30 days and the subsoils from 37 to 121 and even 201 p.p.m. of nitrogen. At the end of 40 days the maximum fixation is 121 p.p.m. and the minimum is 12 p.p.m. In no case during either the 30 or 40-day period did a reverse process set in with sufficient intensity to offset the fixation, so that at the end of 40 days every sample contained more nitrogen present than at the beginning. The nitrification that took place was apparently more rapid during the last ten days of the incubating period than during the first 30 days. There were some cases in which the gain was small, but none showed a loss. When we study the nitrification as it took place in the soil in the field, we find that it proceeds in a more marked degree than in our incubator. The samples of soil taken on 20 May contained from 11 to 25 p.p.m. of nitric nitrogen. On 7 July, samples taken four inches deep ranged from 20 to 27 p.p.m.; by August 9 it had risen to the maximum for the season, ranging from 33 to 85.5 p.p.m. There were 15 composite samples in every set and 20 subsamples in each composite sample. On 2 September we found that the nitric nitrogen had fallen to a range of from 12 to 63 p.p.m. except in one instance in which it reached the individual maximum for the season, 187 p.p.m. From 2 to 16 September, there was a further decrease, and the range was from 13 to 46. No general sets of samples were taken after this date. All of these field samples were taken from the middle of the crest and near the plants in the rows. Vacant spaces and the slopes of the ridges were carefully avoided because our experience has taught us that vacant spaces in the rows, i. e. (fallow) spots in such cultivated ground and the area just a little way above the water line in an irrigating furrow, are places where nitric nitrogen may be very abundant compared with the rest of the soil.

It was not feasible for us to take samples more frequently than we did and we appreciate the fact that the six series of samples represent only the general course of development during the season, and is not a record of the changes that undoubtedly took place in the soil. Our figures represent only the gross results of all of the changes that had taken place in the soil during the interval between the taking of the samples measured by the amount of nitric nitrogen found on the given dates. We have not been able to consider in any manner the flora that brought about these changes. Our results are only the gross results, giving, as said above, simply the general course of the changes going on in the soil, measured by the nitric nitrogen present on certain dates. If the samples had been taken on other dates we would undoubtedly have gotten other results.

Another measure might have been adopted, in fact, we have adopted another measure for the total biological activities in the soil; i. e. the amount of carbon dioxide present in the soil atmosphere, but we have a great deal to do in this direction. The nitric nitrogen has been up to this point a better measure for our specific purpose perhaps than the carbon dioxide would have been, for the nitric nitrogen is the actual source of the nitrogen appropriated by the plant. It does not follow that the carbon dioxide in the soil is of no importance to the vigor and productiveness of the plant, either directly or indirectly, in a variety of ways. The task that we have set ourselves is specifically to determine, if possible, the effects of a large nitrogen supply upon the composition and properties of the potato plant and its tubers.

Under properties we consider, in this case, primarily their susceptibility to disease and this in a very general sense. It is evident why we have addressed ourselves to the questions pertaining to the soil used in which to grow the potatoes, and we think that we have given the soil conditions as fully as is required by our problem, to wit: its composition and its nitrogen fixing and nitrifying capacity, together with the actual amounts of nitric nitrogen available to the plant on our check plots, of which there were 15 in all, at six given dates during the season. At no time was there less than the equivalent of 72 pounds of sodic nitrate per acre in the top four inches of soil, and so small an amount was exceptional. In July this amount was between 250 and 400 pounds, and in August from 300 to 500 pounds, and in September from 250 to 150 pounds, with a strong downward tendency. In a single case of a composite sample we had the equivalent of 1122 pounds of sodic nitrate.

It may be well in this connection to give the amounts of sodic nitrate applied to the different plots in the hope of producing such extreme effects that we might be able to definitely ascribe them to the nitrate added. We applied it at the rate of 200, 400, 600 and 800 pounds per acre. These applications were made immediately after the potatoes were planted and were in addition to whatever may have been formed in the plots during the season. We have, I believe, a very good estimate of the amounts formed, provided that the nitrate added had no effect upon this factor, which, however, is not probable.

So far as the cultivation and irrigation are concerned, the standard practice of the district was followed in detail, so the results obtained have general application to this type of soil.

Mention has already been made of the fact that the 1920 series of experiments was rendered somewhat unsatisfactory by a hailstorm that visited the plots in August and did severe injury to the vines and that, on this account, we did no analytical work on this portion of the crop, but we analyzed the tubers. While I do not know what the effect of such injury to the vines may have had on the compositon of the tubers, I take it for granted that it had some effect and probably a great deal; nevertheless, we analyzed the crop in preference to wholly rejecting the season's work, especially as the changes in the composition of the tubers is assumed rather than known.

ANALYSES OF TUBERS GROWN IN 1920

VARIETY—	Water	Dry* Substance	Ash	Fat	Protein	Crude Fibre	Nitrogen Free Extract	Starch Found
Early Ohio, check	79.18	20.82	1.03	0.09	2.65	0.55	16.50	14.83
Early Ohio, 800-lb. $NaNo_3$	79.68	20.32	1.10	0.12	2.69	0.42	15.90	15.20
Bliss' Triumph, check	81.30	18.70	1.08	0.11	2.68	0.51	13.32	12.88
Bliss' Triumph, 800-lb. $NaNo_3$	81.07	18.93	1.02	0.08	2.77	0.47	14.59	13.75
Rural, check	79.95	20.05	0.94	0.11	2.31	0.51	16.18	16.13
Rural, 800-lb.-$NaNo_3$	80.60	19.40	0.98	0.11	2.71	0.54	15.06	14.49
Downing, check	81.00	19.00	1.03	0.08	2.65	0.52	14.72	14.18
Downing, 800-lb. $NaNo_3$	78.36	21.64	1.00	0.07	2.75	0.49	17.32	15.26
Pearl, Check	79.50	20.50	1.05	0.08	2.44	0.54	15.94	14.54
Pearl, 800-lb. $NaNo_3$	79.20	20.80	1.02	0.07	2.58	0.56	16.56	14.25
Average	79.98	20.02	1.03	0.09	2.62	0.51	15.61	
Average Jordan and Winton	78.89	21.71	0.95	0.10	2.14	0.56	17.36	

*Dry substance was determined at 100 degress with no more than 75 mm. pressure, practically in vacuo.

The average composition of potatoes in their fresh condition, as given by Jenkins and Winton in their "Compilation of Analyses of American Feeding Stuffs" marked "Average" in table is very nearly the same as the average for our ten samples representing five varieties including both early and late sorts. We find the widest divergence in the protein and nitrogen-free extract. The range in the amount of protein in the different samples is from 2.3 to 2.8. The lower of these figures is from a check plot and the higher from one that received sodic nitrate at the rate of 800 pounds per acre. This difference is smaller than we had hoped to find, but it is consistently in favor of the potatoes grown with nitrate throughout the series, and the average stands 2.54 to 2.70 for the series, against 2.14 average given by Jenkins and Winton.

The next point of divergence is found in the case of the nitrogen-free extract for which our average is 1.75 percent lower than the average given by these authors. Our series, however, shows a maximum difference of 4.0 percent or the ranges are from 13.32 to 17.32; theirs is, for raw potatoes, from 14.05 to 19.98 percent. There is again only a very slight difference between the checks and those grown with nitrates, the average is slightly in favor of those grown with nitrates. The differences between the individual pairs, however, are not consistently in one direction, three of them are in favor of the potatoes grown with nitrates and two in favor of the check plots. The figures representing the nitrogen-free extract cover all of the errors of the analysis plus or minus, and the results agree as well as one could expect, but conclusions regarding the effects of the nitrates based upon these differences alone would be, in my opinion, unjustified.

HOW OUR CHECK PLOTS FAILED US

The question of how much importance one is to attach to any differences, large or small, shown by such analysis or what interpretation, if any, is to be made, is an open one, especially in the light of the facts exhibited by the six sets of samples taken from check plots during the season, 7 July to 16 September, according to which there was during a period of three or four weeks nitric-nitrogen equivalent to as much sodic nitrate as we applied to three out of four of the series, so that the assumption that our check plots were grown without the application of nitrates is true only in a very technical sense; i. e. we did not apply any nitrates but there was during this period the equivalent of from 350 to 500 pounds of sodic nitrate present in the top four inches of the soil, and the samples were carefully taken to avoid exaggeration of the amount present. We intended that the check plots should be grown without any application of nitrates or any undue amount of them. It is evident that we did not realize our expectations in this respect, and all of our potatoes were grown with an abundant supply of nitrates only some had more than others for we added sodic nitrate at the rate of 200, 400, 600 and 800 pounds to the acre, but an exceptional result in the case of one check plot gave results equivalent to 1122 pounds of sodic nitrate per million in the top four inches of the soil, which is greater than the largest amount that we applied. Under these conditions our checks failed us, so far as our purpose was concerned, and we, in the end, are compelled to compare potatoes grown with a big supply of nitrates with such as presumably had a greater supply of them and we are not comparing potatoes grown with and without any unusual supply of them. Under these conditions the potatoes should show the same characteristics and composition varying only in some small degree according as the sample happened to have enough or not quite enough to produce a maximum effect. We were endeavoring to find out, first, what this effect actually is and its maximum. It is evident that we cannot, in this way, satisfactorily establish either the character or the extent of these effects. If we insist upon clear and definite results attributable to the amounts of nitrate that we apply, we shall have to repeat the whole series of experiments under different soil conditions. All of the results that we have gotten or may get by continuing our experiments on this soil will be simply ascertaining the differences in the degrees in which excessive, but unknown, quantities of nitrates have affected the composition and properties of the potatoes produced.

We shall give, at another time, analyses of potatoes from other sections of the State grown with and without irrigation. In this way we shall be able to present characteristics of various potatoes grown elsewhere with those of ours, grown at Greeley, but this will be far from satisfactory, for we cannot give any of the soil factors. We can only assume that they were favorable and that the soils do not show either the fixing or nitrifying power of our Greeley soil. Still, we shall give analyses of such samples depending upon the characteristics of the locality as sufficient guides in the different cases. We cannot, of course, do this for the crop of 1920.

There remain only two points in the analysis of these potatoes to examine further,—the ash, and the forms in which the nitrogen may be present. We shall take up the latter next. From the ordinary analyses, to which I have added the starch determinations, it is evident that no error is made when we consider the nitrogen-free extract as consisting wholly of starch.

FORMS OF NITROGEN PRESENT

In independent investigations, made with the purpose of detecting sugars, dextrine, etc., we have failed to find these constituents which are sometimes given, but not, so far as I know, in fresh potatoes. The agreement between the determinations of the so-called nitrogen-free extract and starch, when one considers the manner in which the former is arrived at, and the difficulties of the latter determination, is very good indeed and leaves no reasonable ground for doubting their essential identity. The only differences in these analyses, as stated in the table which can be attributed to the nitrate applied, is in the amount of protein present. We have endeavored to ascertain whether there are any differences in the forms in which the nitrogen is present in the potatoes that may show whether the nitrate applied, in this case at the rate of 800 pounds per acre, has had any influence in this respect. The average total nitrogenous constituents in our potatoes is somewhat higher than that given by Jenkins and Winton, still it does not reach 2.7 percent, so it is evident that we shall have to deal with relatively small differences, as according to this average the total nitrogen is 0.42 percent of the potato, but even this is nearly one-fifth higher than the average given by Jenkins and Winton.

THE FORMS OF NITROGEN IN POTATOES

	Total Nitrogen Percent	Amm. and Amid Nitrogen Percent	Amino Nitrogen Percent	Albumin Nitrogen Percent	Peptose Nitrogen Percent	Petene Nitrogen Percent	Nitric Nitrogen Percent
Early Ohio, check	0.4234	0.0638	0.0968	0.1255	0.0469	0.0138	0.0063
Early Ohio, 800-lb. NaNo$_3$	0.4301	0.0653	0.1020	0.1380	0.0451	0.0186	0.0075
Bliss' Triumph, check..	0.4284	0.0545	0.0769	0.1434	0.0801	0.0004	0.0062
Bliss' Triumph, 800-lb. NaNo$_3$	0.4425	0.0587	0.0864	0.1831	0.0576	0.0174	0.0082
Rural, check	0.3702	0.0628	0.0988	0.1168	0.0484	0.0358	0.0004
Rural, 800-lb. NaNo$_3$....	0.4333	0.0638	0.0900	0.1292	0.0461	0.0279	0.0025
Downing, check	0.4242	0.0584	0.0859	0.1335	0.0384	0.0096	0.0030
Downing, 800-lb. NaNo$_3$.	0.4399	0.0683	0.1090	0.1586	0.0762	0.0270	0.0049
Pearl, check	0.3090	0.0561	0.0872	0.1176	0.0556	0.0188	0.0002
Pearl, 800-lb. NaNo$_3$....	0.4130	0.0581	0.0856	0.1240	0.0846	0.0446	0.0013

In this table we find that the application of sodic nitrate at the rate of 800 pounds per acre has produced an increase in the total nitrogen present and has brought about changes in the relative amounts of the different forms in which it exists in the potato. Some things that we have said in preceding paragraphs concerning the checks as being unsatisfactory standards and the reasons for this must be considered in this connection. The checks themselves average high in total nitrogen, 0.418 against 0.342 for the average given by Jenkins and Winton, which is higher than others that I find; for instance, Langworthy is quoted by Stewart as giving the protein of potatoes as purchased as 1.8 percent which would correspond to 0.288 percent of nitrogen, which is much below our average check, 0.418 percent. The average for the total nitrogen for all varieties that received a dressing of nitrate at the rate of 800 pounds per acre is 0.431 or 0.013 higher than the average of those that received no application of nitrates. This difference is considerably in favor of the potatoes that received the application of nitrates in each of the individual pairs. The albumin nitrogen in the individual pairs is also consistently larger in those grown with the application of the nitrate. The same is true in the case of the amid and amino nitrogen, with two exceptions in the case of the amino nitrogen. So far as this series of samples is concerned, the most positive effect of the nitrate is shown in the amount of the nitric nitrogen. The maximum difference shows six times as much in those from the plot with nitrate as in those from the check plot. These results are, under the conditions, as decisive as one could expect; in fact, rather more so. It, however, is true, that the general characters and quantities of the nitrogenous constituents of these potatoes are so similar that they are not suited, in any measure, for the purpose that we grew them; i. e., to ascertain whether the application of these quantities of nitrates would so modify the composition that it would increase their susceptibility to disease and impair their power of resistance when attacked. This similarity in composition is what we should expect since we find in July, August and the first half of September the nitrates ranging from 250 to 500 pounds in the top four inches of these check plots, with the exceptional result of over 1100 pounds for one of them. The samples were taken 14 days apart and always avoiding the more favorable conditions for the formation of nitrates. In these considerations we are tacitly assuming that there were no nitrates available to these potatoes other than those that we found in the surface four inches of this soil which cannot be true, and further, that there were no variations in the 14 days intervening between the dates of our sampling which is also almost certainly a false assumption. We applied our nitrate immediately after the potatoes were planted, and trusted to cultivation and irrigation to bring it within the feeding area of the plant. We tried to distribute it evenly over the whole surface. We do not know whether the time of distribution was the most favorable nor the proportion of it that ever became actually available. We were influenced in choosing the time of application and the amount applied by our observations on other crops. We found, for instance, that 250 pounds of sodic nitrate per acre applied to wheat at the time of planting produced incomparably larger effects than a further addition of 500 pounds during the season. Again, we found that from 800 to 1000 pounds produced the maximum deleterious effects upon a beet crop, but in neither of these cases did we have a continuous excessive supply furnished by the soil itself. In the case of the wheat crop, we had in the surface foot of soil in August, 1915, at the time of harvest, the equivalent of 19.5 pounds of sodic nitrate per acre, whereas the amount present in the check plots on which we grew potatoes was from 300 to 500 pounds per acre in the top four inches of soil for the month of August, 1920. The results obtained under these conditions are as great and as decidedly positive as we could expect and indicate clearly that the potato is, in regard to composition at least, sensitive to the effects of the nitrate that may be available. A further suggestion afforded by the preceding facts is that Greeley, owing to the character of its soil, is not the place where we may hope to obtain decisive answers to the questions to which we have addressed ourselves. As we shall present the data obtained in succeeding years, in a later bulletin, we defer further comment on this subject.

ASH CONSTITUENTS

In a similar study made on sugar beets and also on wheat, two very dissimilar crops, we found that nitrate of soda tended to increase the total ash, to suppress the phosphoric acid and to modify the quantitative relations of the different forms in which nitrogen is present. In the beet it raised the total nitrogen from 0.15 percent to 0.27 calculated on the fresh beet, and depressed the phosphoric acid, calculated on the pure ash, from 13.9 to 2.89 percent. Its effect upon the amount of potash present was generally to depress it. The pure ash of our standard beets carried about 52.5 percent of potash, and beets grown with nitrates from 29 to 38 percent. But when the potash is calculated on the green weight there is usually more in the beets grown with nitrate. The effects of nitrates on the ash of wheat was in the same direction but very much smaller, and increased the potash in the wheat plants.

NITRATES DEVELOPED IN OUR CHECK PLOTS

The data that we have obtained for potatoes are not very satisfactory because we have no data for what we may call standard potatoes for Colorado. It is true that we grew our checks for the purpose of having data that would show by comparison the effects of the nitrates supplied. Reference to the results obtained in determining the nitric nitrogen in the soil of these check plots makes it clear that we had in the top four inches of soil of these check plots throughout July and August nitric nitrogen equivalent to from 160 to 660 pounds of sodic nitrate per acre, taking the weight of this four inches of soil at 1,333,333 pounds. The samples of soil taken in May to a depth of one foot showed from 66 to 120 pounds. These samples were taken shortly after the land had been plowed to a depth of nine inches. As the results stand, it would have been better if we had taken samples in June and gotten an idea of the rate of increase in the nitrates between 20 May and 7 July, but during this period we took no samples. On 20 May, the average content of nitric nitrogen in the six samples of surface soil taken to a depth of one foot was 15.9 p.p.m. and on 7 July the average of the 15 samples taken to a depth of four inches was 25.2 p.p.m. This increase is suggestive of a very active nitrifying process, and it continued throughout the growing season so that our check plots were supplied with nitrates from a natural source equivalent to an application of at least from 300 to 500 pounds of sodic nitrate. Our applications made immediately after planting ranged from 200 to 800 pounds per acre. It is evident that under these conditions we can have only that increased effect of the nitrates that might be caused by the addition of these quantities to that produced by those naturally furnished by the soil, and this is true of all and each of the properties of the potatoes, including the growth, the susceptibility to disease, and composition of the vines as well as the composition, the keeping and cooking qualities of the tubers. Of course, our aim was to apply so much nitrate that we would produce an exaggerated effect, so much so that there could be no question about the cause of the effect produced.

We, on the other hand, assumed that our check plots would produce potatoes such as would be produced with only a small amount of nitrates,—less than 40 p.p.m. Instead of this, we find from 300 to 500 p.p.m. of these salts and in an extreme case 1122 p.p.m. This was not in a single sample but in a composite one made up of 20 sub-samples taken to a depth of four inches. Under these conditions one cannot deny the possibility that the checks may show a maximum effect of the nitrates in which event our whole series of experiments would be inconclusive. •At the very best, the differences that we had hoped to obtain will be greatly reduced and the physiological and pathological differences that we had hoped to observe may have been wholly obliterated.

ASH OF POTATOES GROWN WITH AND WITHOUT APPLICATION OF SODIC NITRATE

VARIETY	EARLY OHIO		BLISS' TRIUMPH		RURAL	
Fertilizer Per Acre	Check	800-lb. $NaNo_3$	Check	800-lb. $NaNo_3$	Check	800-lb. $NaNo_3$
Air Dry	Percent	Percent	Percent	Percent	Percent	Percent
Dry Matter	21.70	21.20	19.60	20.11	20.80	20.30
Ash in dry matter...	4.75	5.19	5.53	5.69	4.54	4.84
Ash in fresh potato..	1.029	1.109	1.084	1.144	0.943	0.983
Moisture 200°C	0.481	1.027	0.881	1.343	0.713	0.901
Volatile above 200°C	4.249	2.160	3.284	2.897	2.625	3.749
Carbon	0.000	0.034	0.000	0.253	0.059	0.089
Sand	0.286	0.592	0.886	0.451	0.245	0.308
Silicic acid	0.716	0.940	1.107	0.708	0.979	0.745
Carbonic acid	13.560	14.570	13.380	14.380	16.440	17.220
Chlorin	3.170	2.901	3.601	3.462	1.983	1.875
Sulfuric acid	4.920	4.950	4.858	4.653	4.195	4.086
Phosphoric acid	14.880	13.656	13.901	13.356	12.526	11.233
Ferric oxid	0.192	0.183	0.199	0.268	0.190	0.163
Aluminic oxid	0.210	0.281	0.406	0.182	0.258	0.133
Manganic oxid (br)..	0.060	0.061	0.037	0.028	0.047	0.023
Calcic oxid	1.492	1.517	1.557	1.602	1.236	1.716
Magnesic oxid	3.539	3.512	3.823	3.771	3.253	3.115
Sodic oxid	0.383	1.057	0.416	0.885	10.340	10.718
Potassic oxid	53.231	53.369	52.907	52.289	52.286	54.606
Sum	101.364	100.815	101.243	100.528	100.376	100.680
O equivalent to Cl...	0.715	9.654	0.812	0.781	0.447	0.423
Total	100.649	100.161	100.431	99.747	99.929	100.257

ASH OF POTATOES GROWN WITH AND WITHOUT APPLICATION OF SODIC NITRATE (Continued)

VARIETY Fertilizer Per Acre	DOWNING Check	DOWNING 800-lb. $NaNo_3$	PEARL Check	PEARL 800-lb. $NaNo_3$
Air Dry	Percent	Percent	Percent	Percent
Dry matter	22.600	19.550	21.400	21.600
Ash in dry matter	4.557	5.110	4.614	4.716
Ash in fresh plant	1.031	0.999	0.987	1.019
Moisture 200°C	0.443	0.380	0.134	0.296
Volatile above 200°C	2.682	2.552	2.661	2.155
Carbon	0.000	0.029	0.387	0.182
Sand	0.588	0.571	0.477	0.451
Silicic acid	0.958	0.870	1.000	0.968
Carbonic acid	16.610	19.020	17.980	18.720
Chlorin	2.048	1.721	2.102	1.934
Sulfuric acid	4.484	3.984	4.682	4.506
Phosphoric acid	11.601	10.637	10.664	9.673
Ferric oxid	0.225	0.185	0.201	0.228
Aluminic oxid	0.173	0.292	0.281	0.095
Manganic oxid (br)	0.083	0.058	0.071	0.057
Calcic oxid	1.862	1.967	1.253	1.528
Magnesic oxid	3.570	3.300	3.509	3.502
Sodic oxid	0.484	0.201	0.062	0.484
Potassic oxid	53.942	54.370	54.753	56.171
Sum	101.753	100.137	100.217	100.950
O equivalent to Cl	0.462	0.388	0.474	0.436
Total	100.291	99.749	99.748	100.514

OTHER ANALYSES OF POTATO ASHES

The few analyses of potato ash that I have found are not as full as one could wish and it is evident from what I have already said concerning the conditions under which our checks were grown that it would be wrong to consider them as representative of potatoes grown with a normal amount of nitrate available throughout their growing period. We see that the application of 800 pounds per acre of sodic nitrate shows the effect of this salt upon the amount of phosphoric acid and potash in the ash. The checks being regularly higher than the nitrate samples in phosphoric acid and lower in potash. The ash of the check samples are themselves lower than the averages given for the phosphoric and higher than those given for potash in potato ashes that I have found. In Leach's "Food Composition and Analysis" revised by Winton, p. 311, is given an average of 53 analyses taken from Koenig and presumably of German potatoes, which is as follows: Ash in dry substance 3.77, Potash 60.37, Soda 2.62, Lime 2.57, Magnesia 4.69, Iron oxid 1.18, Phosphoric acid 17.33, Sulfuric acid 6.49, Silica 2.13, Chlorin 3.11. I do not think that comparisons in this case are of much value, but it will be noticed that the ash in the dry matter, in our case air-dried, is much higher. Our average is 5.09 against 3.77. The phosphoric acid, P_2O_5, is decidedly lower,—our average for the ten samples analyzed even after the carbon dioxid, sand, and moisture at 200 deg. C. have been deducted, or in other words the pure ash, gives an average of 14.57 against 17.33. The actual amount of phosphoric acid removed per 1000 pounds of our potatoes is greater than that removed by the German potatoes owing to the higher content of ash. The potash in the pure ash of our potatoes, as shown by the average of the ten analyses, is 65.12 percent against 60.37 percent for the German potatoes. As no facts are known about the soil, fertilization or varieties these comparisons have only a small and general interest.

AVERAGE PHOSPHORIC ACID AND POTASH IN POTATOES

I called attention in a previous paragraph to the effect of the nitrates applied on the phosphoric acid and potash in the ash of beets and wheat. The statement is made that it suppresses the former, and either has no effect upon or increases the percentage of the latter. These effects are as marked in the case of the potato as in either that of wheat or the sugar beet.

It may be well to mention the fact that we are comparing the fruit, in the case of wheat, at least for the most part, with parts of the plant in the cases of the beets and potatoes. We arrange the results obtained, calculated on the pure ash, in the following table:

PHOSPHORIC ACID AND POTASH IN PURE ASH OF POTATOES GROWN WITH AND WITHOUT NITRATES

		Phosphoric Acid Percent	Potash Percent
Early Ohio	Check	17.41	60.96
Early Ohio	800-lb. $NaNo_3$ per acre	16.29	64.45
Bliss' Triumph	Check	16.38	61.18
Bliss' Triumph	800-lb. $NaNo_3$ per acre	15.93	63.08
Rural	Check	15.16	63.45
Rural	800-lb. $NaNo_3$ per acre	13.77	66.95
Downing	Check	14.13	66.30
Downing	800-lb. $NaNo_3$ per acre	13.30	67.89
Pearl	Check	13.33	67.25
Pearl	800-lb. $NaNo_3$ per acre	12.09	69.73

The average phosphoric acid for the five check plots is 15.28 percent, that for the five plots receiving 800 pounds $NaNO_3$ per acre is 14.28 percent. The average potash for the same is 63.83 percent for the check, and 66.42 percent for those that received 800 pounds of nitrate.

The season of 1920 was an unfortunate one for us in that the vines were so badly damaged by a hail storm in August that we did not use them in our investigation. How much this affected the composition of the tubers I do not know, but preceding statements show that whatever these effects may have been, those of the added nitrates were not wholly concealed. The effect of the nitrates was, after all, the main object that we had in view. Still it was regrettable that the vines were so badly damaged.

SUMMARY

We obtained by our season's work a knowledge of the composition and deportment of the soil in which we were to conduct further experimentation. In this respect the main points were that the chemical composition was satisfactory, but the physical properties were disadvantageous. It was, however, the only land at our disposal.

The fixing and nitrifying capacities of the soil were found to be very considerable. The maximum increase in the total nitrogen in the surface soil on incubation for 40 days was 110 p.p.m., and in the subsoil 121 p.p.m.; the maximum increase in nitric nitrogen in the same time was 39 p.p.m. for the surface soil and 25 p.p.m. for the subsoil.

The average nitric nitrogen found in our western series, 9 checks, on 9 August was 66.1 p.p.m. taken to a depth of 3 to 4 inches, and in our eastern series, 6 checks, was 51.0 p.p.m. On 2 September, we found a slight falling off except in one check which had risen to 187.0 p.p.m., which was the maximum found in any check plot during the season. This was a composite sample made up of 20 subsamples.

The nitric nitrogen in top 3-4 inches of soil during July and August in the western series was equivalent to 286.8 pounds of sodic nitrate, and in the eastern series 141.4 pounds. These quantities represent a continuous supply of nitrates during these two months. We applied 200, 400, 600 and 800 pounds per acre at the time of planting, expecting to so exaggerate the effects of this salt that we might recognize it unmistakably.

In the study of this subject in the case of wheat, we found that 250 pounds per acre produced almost as large an effect as 750 pounds, though the 250 pounds were applied at the time of planting and the 750 pounds were added in three applications of 250 pounds each at intervals of four weeks.

Our western series had a continuous supply in the case of the check plots of 286.8 pounds in the top 3-4 inches during July and August, and on 16 September the average found for the check plots was 210.6 pounds for the same depth. Under these conditions there remained nothing for us to do except to find out if possible whether the application of 800 pounds of nitrate per acre at the time of planting had produced a big enough effect to be detected by analytical methods. The ordinary analysis of the tubers gave the following average results for the five varieties used:

	Water	Dry Matter	Ash	Fat	Pro-tein	Crude Fibre	Nitrogen Free Extract
Checks	....80.18	19.82	1.02	0.10	2.54	0.53	15.24
Nitrates	....78.78	20.22	1.02	0.09	2.74	0.50	15.88

These averages are so nearly identical that only in the case of the protein can the differences be considered as falling outside of the analytical errors. This means that our check potatoes were typical nitrate potatoes, and that those grown with the addition of 800 pounds more nitrates were only a little richer in total nitrogen than those grown with the natural supply. The average protein in potatoes given by Jenkins & Winton is 2.14, and by Langworthy for potatoes purchased in the market, as 1.8 percent. These facts make clear the statement of a former paragraph, that our checks failed us almost completely.

When we come to study the distribution of the nitrogen in these potatoes, we find the same close agreement in the figures obtained which is a fact to be expected from the data already given. As there is but little nitrogen in the potato tuber, from 0.288 to 0.44 in the dry matter, there is not much for any one part when this is divided into six or seven parts, and a difference constantly in a given direction is more significant for us as indicating the effects of the nitrates than its amount, especially in view of the continuous and liberal supply of nitrates formed in the soil of our check plots.

Our attempts to determine ammonia nitrogen in the tubers of this crop were unsatisfactory. This may have been due, at least in part, to the manner of storage, but we have included it, if present, in the amid nitrogen. The other determinations are as satisfactory as the methods adopted justify us in expecting. The 800 pounds of sodic nitrogen increased all the forms of nitrogenous compounds determined, some of them relatively a great deal. The potatoes grown on our check plots all showed the presence of nitric nitrogen but in no case so much as those of the nitrate plots, in some cases only a sixth as much. The amino nitrogen is very much greater in quantity, and in two instances the check contained more than the nitrate plot, but in the other three pairs it was greater in the nitrate plot. The albumin nitrogen which was approximately 35 percent of the total was uniformly higher in those from the nitrate plots.

The average starch content of the potatoes from the checks and nitrate plots is practically identical; 14.51 for the check plots and 14.56 for nitrate plots. The individual pairs are, considering the difficulties of this determination, very close together.

The ash of our potatoes is rather high considering the small amount that usually occurs in the tubers. The average given by Jenkins & Winton is 0.95, and A. Mayer gives 0.39, presumably for German potatoes, while ours has 1.03 percent in the dry matter. The average phosphoric acid in the ash given by A. Mayer is 15.2, while the average for our ten samples of ash is 12.2 percent. This is the relative amount in the ash of the dry matter. The absolute amount removed by an equivalent of our potatoes is more than twice that of the German potatoes.

We found that the application of nitrates depressed the phosphoric acid but increased the potash in the ash of sugar beets, also in that of wheat. The same result is found again in the potatoe. It is true that we have no analysis of potato ash that we can consider standard; all that we can say is that our data prove conclusively that the application of 800 pounds of sodic nitrate per acre has depressed the phosphoric acid and increased the potash in the ashes of all varieties to a greater extent than the quantities that were available to the potatoes that grew on the check plots.

The indications are that the composition of the potato is radically modified by an excess of nitrates.