RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

GROWTH OF POTATOES,

FOR TWELVE YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JULY 27, 1888,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

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INTRODUCTION.

My lecture here last year was devoted to the consideration of the conditions and the results of growth of the pre-eminently sugar-yielding root-crops, and I have now to direct your attention to the conditions and the results of growth of the pre-eminently starch-yielding Potato.

From the point of view of the vegetable physiologist the Potato is not a root, but a tuber; but from the point of view of the agriculturist it might well be classed as a root-crop.

It does not fall within my scheme of illustration, to discuss at any length the history of the Potato as a European crop. It will suffice to say that it seems to have been introduced into this country from Virginia, just about three centuries ago; though it is probable that it had been introduced into Portugal, and thence into other continental countries, some years earlier.

It is also outside of my plan to enter into a consideration of the comparative characters of the enormous number of varieties now cultivated; or of the differences in the treatment of the crop, according to soil, climate, and other local circumstances.

My special object is to show the general requirements of the crop, both actually, and as compared with other crops, and the actual and comparative characters and composition of the product obtained.

As in my lectures on other crops, I propose to draw my illustrations, mainly from the results of Field experiments on the growth of the Potato by different manures, for a number of years in succession on the same land, at Rothamsted, and from those of collateral investigations into the composition of the produce, made in the Rothamsted Laboratory. I shall, however, bring to my aid the results of other investigators, so far as the subject may require, and my limits as to time and space will permit.

PRODUCE WITHOUT MANURE, AND WITH VARIOUS ARTIFICIAL MANURES.

First as to the average produce of Potatoes, per acre, per annum, without manure, and with different descriptions of manure.

Table I. (p. 3), shows the results obtained without manure, and by six different descriptions of artificial manure; and Table II. (p. 7), shows the results without manure, and with farm-yard manure, either alone, or with other manures.

In each case, the particulars given are, the average annual amounts obtained per acre, of good, of small, and of diseased Potatoes, the total amount of tubers, and the percentage of diseased in the total produce. In the case of the artificial manure series, these particulars are given, for the first four, the second four, the third four, and the total period of twelve years, of the continuous growth of the crop on the same land; and in the case of the farm-yard manure series, the results are given for six, six, and twelve years.

The artificial manure series comprises the following conditions as to manuring:—

1. Without manure.
2. Superphosphate of lime alone.
3. A "mixed mineral manure," containing superphosphate, and salts of potash, soda, and magnesia.
4. Ammonium-salts alone, supplying 86 lbs. of nitrogen, per acre per annum.
5. Nitrate of soda alone, also supplying 86 lbs. of nitrogen, per acre per annum.
6. The ammonium-salts, and the "mixed mineral manure" together.
7. The nitrate of soda, and the "mixed mineral manure" together.

It should be added, that the description of Potatoes grown during the first four years was the "Rock," but subsequently the "Champion."

The last column but one of Table I. shows that, without manure, with ammonium salts alone, and with nitrate of soda alone, the average produce of tubers was less over each succeeding period of four years. On the other hand, with the superphosphate alone, with the mixed

TABLE I.
POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Manures and Produce per acre per annum; 12 years, 1876-1887.

	Good,		Small.		Diseased.		Total.		Per cent. Diseased in Total.
	Tons.	cwts.	Tons.	cwts.	Tons.	cwts.	Tons.	cwts.	Per cent.
UNMANURED. (Plot 1.)									
Averages: 4 years, 1876-1879	2	3⅞	0	6⅛	0	2¾	2	12¾	5·14
Averages: 4 years, 1880-1883	1	12¾	0	4⅞	0	0⅝	1	18¼	1·63
Averages: 4 years, 1884-1887	1	3⅝	0	4	0	0⅜	1	8	1·43
Averages: 12 years, 1876-1887	1	13½	0	5	0	1¼	1	19¾	3·15
SUPERPHOSPHATE OF LIME. (Plot 9.)									
Averages: 4 years, 1876-1879	2	18⅝	0	8⅜	0	4⅞	3	11⅞	6·89
Averages: 4 years, 1880-1883	4	9⅜	0	5	0	2⅛	4	16½	2·16
Averages: 4 years, 1884-1887	2	7⅛	0	3⅝	0	1	2	11¾	1·98
Averages: 12 years, 1876-1887	3	5	0	5⅝	0	2¾	3	13⅜	3·66
MIXED MINERAL MANURE. (Plot 10.)									
Averages: 4 years, 1876-1879	3	3¾	0	6½	0	5¼	3	15½	6·90
Averages: 4 years, 1880-1883	4	9⅞	0	4½	0	1⅝	4	16	1·64
Averages: 4 years, 1884-1887	2	9¾	0	3⅝	0	1	2	14⅜	1·87
Averages: 12 years, 1876-1887	3	7¾	0	4⅞	0	2⅝	3	15¼	3·45
AMMONIUM SALTS = 86 lbs. NITROGEN. (Plot 5.)									
Averages: 4 years, 1876-1879	2	7⅛	0	6⅝	0	4⅜	2	18⅛	7·45
Averages: 4 years, 1880-1883	1	16½	0	6½	0	0¾	2	3¾	1·76
Averages: 4 years, 1884-1887	1	9¾	0	5¼	0	0½	1	15½	1·36
Averages: 12 years, 1876-1887	1	17¾	0	6⅛	0	1⅞	2	5¾	4·06
NITRATE OF SODA = 86 lbs. NITROGEN. (Plot 6.)									
Averages: 4 years, 1876-1879	3	2	0	6	0	6¾	3	14¾	9·09
Averages: 4 years, 1880-1883	2	0¾	0	6	0	0½	2	7¼	1·17
Averages: 4 years, 1884-1887	1	11	0	3⅞	0	0⅜	1	15¼	1·16
Averages: 12 years, 1876-1887	2	4⅝	0	5¼	0	2⅝	2	12½	4·93
AMMONIUM SALTS = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 7.)									
Averages: 4 years, 1876-1879	5	14	0	8¾	0	15¼	6	18	11·08
Averages: 4 years, 1880-1883	7	19⅝	0	6½	0	8⅝	8	14¾	4·95
Averages: 4 years, 1884-1887	4	3⅛	0	6¼	0	1⅜	4	10¾	1·49
Averages: 12 years, 1876-1887	5	18⅞	0	7¼	0	8⅜	6	14½	6·26
NITRATE OF SODA = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 8.)									
Averages: 4 years, 1876-1879	5	19	0	8	0	18⅝	7	5⅝	12·82
Averages: 4 years, 1880-1883	7	10½	0	6	0	7¾	8	4¼	4·70
Averages: 4 years, 1884-1887	4	2¾	0	5	0	1½	4	9¼	1·73
Averages: 12 years, 1876-1887	5	17⅜	0	6⅜	0	9¼	6	13	7·00
SUMMARY. AVERAGE 12 YEARS. 1876-1887.									
Unmanured	1	13½	0	5	0	1¼	1	19¾	3·15
Superphosphate	3	5	0	5⅝	0	2¾	3	13⅜	3·66
Mixed Mineral Manure ..	3	7¾	0	4⅞	0	2⅝	3	15¼	3·45
Ammonium Salts alone ..	1	17¾	0	6⅛	0	1⅞	2	5¾	4·06
Nitrate of Soda alone	2	4⅝	0	5¼	0	2⅝	2	12½	4·93
Ammonium Salts and Mixed Mineral Manure ..	5	18⅞	0	7¼	0	8⅜	6	14½	6·26
Nitrate of Soda and Mixed Mineral Manure ..	5	17⅜	0	6⅜	0	9¼	6	13	7·00

mineral manure alone, with the ammonium salts and mixed mineral manure together, and with the nitrate of soda and the mixed mineral manure together, there was more produce over the second four years than over the first; but there was a marked reduction over the third four years. It is evident, therefore, that the falling off over the second four years in the other cases was not to be accounted for by less favourable seasons only. The conclusion is rather, that by the continuous growth of the crop without manure, or by nitrogenous manures alone, the available supplies of the necessary mineral constituents within the soil, became relatively deficient.

But the great decline over the third four years, under all conditions of manuring, even where there was a full supply of both nitrogen and mineral constituents, shows that the seasons were then less favourable for luxuriant growth. Doubtless, too, with the mineral manures alone, the available supply of nitrogen within the soil, and with the nitrogenous manures alone, the available supply of mineral constituents, had become deficient.

A point of considerable interest brought to view in the last column of the Table is, that there was, under every condition of manuring, a very much larger proportion of diseased tubers over the first four years, when the "Rock" was grown, than afterwards with the "Champion." The very bad result over the first four years was, however, doubtless in great measure due to the character of the seasons also, which included some exceedingly wet and unfavourable ones. With the "Champion," there was, upon the whole, a less proportion of diseased tubers over the third than over the second period of four years. It is true, that the later years were generally drier, and therefore less favourable, both for luxuriance of growth, and for the development of the disease. Nevertheless, it is of interest to observe that the amount of disease was not enhanced by the continuous growth of the crop on the same land, as is frequently assumed to be the case. It is further of interest to note that, with the highest manuring, and the most luxuriant growth, that is where ammonium salts or nitrate of soda, and the mixed mineral manures, were used together, there was, over the second four years, even with the "Champion," a much higher proportion of diseased tubers than with any of the other manures; though, over the third period, of drier seasons, the proportion was about as low as under the other conditions of manuring.

In the summary at the bottom of the Table is given the average produce over the total period of twelve years, under each of the different conditions as to manuring. It will suffice to call special attention to the column showing the total produce of tubers—good, small, and diseased—and to the last column, showing the average percentage of diseased tubers, under each condition of manuring.

In the first place, the average produce over twelve years without any manure, is not quite 2 tons per acre; and it will be remembered that there was a considerable decline from period to period under this exhausting treatment. Nevertheless, as will be seen further on, this low yield without manure, for twelve years in succession on the same land, is about as much as the average produce under ordinary cultivation in the United States, and nearly two-thirds as much as in some important European countries.

By superphosphate of lime alone the produce is raised from an average of scarcely 2, to nearly 3¾ tons; and by a mixed mineral manure, containing, besides superphosphate of lime, salts of potash, soda, and magnesia, to just over 3¾ tons, that is to very little more than by the superphosphate alone. It is evident, therefore, that up to this amount of production, the character of the exhaustion induced by the growth of the crop on this land, which was, agriculturally speaking, in a somewhat exhausted condition, was much more that of available phosphoric acid than of potash, or the other bases.

In reference to this increase of produce of Potatoes by mineral manures alone, it may be observed that the result is quite consistent with that obtained with root-crops having comparatively shallow root-development; and in such cases the source of the nitrogen is chiefly the store of it in the surface soil. The beneficial effects of mineral manures, and especially of phosphates, are indeed observed generally with ripened as well as with succulent crops which are spring sown, and which have, with a short period of growth, comparatively superficial rooting, and which rely therefore much on the stores of the surface soil.

It is remarkable that there is much less increase of produce of Potatoes by nitrogenous manures alone than by mineral manures alone.

Thus, by ammonium salts alone there is an average produce of scarcely 2 tons 6 cwts., or only about 6 cwts. more than without manure; and with nitrate of soda alone there is an average of only 2 tons 12½ cwts. per acre. The better result by nitrate of soda than by ammonium salts is doubtless due to the nitrogenous supply being more immediately available, and more rapidly distributed within the soil, and so inducing a more extended development of feeding root.

These negative results by the nitrogenous manures alone, confirm the conclusion that by the continuous growth of the crop on this land, it was the available supply of mineral constituents within the root-range of the plant, more than that of nitrogen, that became deficient.

The last two lines of the Table show, that with the mixed mineral manure and ammoninm salts together, there was an average of about 6 tons 14½ cwts., and with the mixed mineral manure and the same amount of nitrogen as nitrate of soda, an average of 6 tons 13 cwts.; that is, nearly twice as much as with the mineral manure alone, and much more than twice as much as with the nitrogenous manure alone. These amounts, it may be observed, are higher than the estimated average produce of either Division of the United Kingdom; indeed, more than one and a half time as high as in Ireland in recent years. At any rate the amounts of produce obtained by the mixture of both mineral and nitrogenous manures are sufficient to show that, although the land is by no means specially adapted for Potatoes, the results may be taken as normal and trustworthy; and as fairly indicating the characteristic manurial requirements of the crop; and the conclusion is that, in an agriculturally exhausted soil, both mineral and nitrogenous manures are required to give full crops.

Finally, in reference to this summary of the results, the last column shows the average percentage of diseased tubers under each of the several conditions as to manuring. It is seen that, without manure, and with purely mineral manures, the proportion of diseased tubers is much less than where nitrogenous manures were applied; and again, that it was less where the nitrogenous manures were applied alone, than when in conjunction with mineral manures; and where, consequently, the luxuriance of growth, and the amounts of produce, were the greatest. To this result I shall have to refer again further on.

PRODUCE WITHOUT MANURE, AND WITH FARM-YARD MANURE.

Table II. (p. 7), gives the results obtained by farm-yard manure, alone, or with other manures, compared with those without manure. It will be seen that the average produce per acre, per annum, is not, as in the case of the artificial mauure series, given for the first, second, and third periods of four years each, and for the twelve years, but for six, six, and twelve years; there having been, as the Table shows, a change in the manuring, in two cases after six years, and in the third after seven years; and, for comparison with the manured plots, the produce without manure is now also given for six, six, and twelve years. It is to be understood, however, that, as in the other experiments, so in these, the "Rock" was grown in the first four years, and the "Champion" afterwards.

As before, we may confine detailed attention to the column of average total produce of tubers—good, small, and diseased, together—and to the last column, showing the average percentage of diseased Potatoes in the total produce.

As already shown, the average produce without manure declined considerably over the later years.

The second division of the Table shows that, with an annual application of 14 tons farm-yard manure per acre, supplying perhaps about 200 lbs. of nitrogen per acre per annum, there was an average produce over six years of only about 5¼ tons; and, as shown in the third division, the addition of superphosphate of lime raised the produce to scarcely 5 tons 12 cwts., or by only about 7 cwts. The fourth division shows, however, that by the further addition of nitrate of soda, supplying 86 lbs. of nitrogen per acre per annum, in a much more readily available condition than most of that in the farm-yard manure, the average annual produce of tubers was raised to 7 tons 2 cwts., or by 1½ ton more.

Comparing these results with those obtained by artificial manures alone, we find that farm-yard manure, which, besides an abundance of mineral matters, and a large amount of organic substance rich in carbon, supplied annually about 200 lbs. of nitrogen, gave considerably less produce than an artificial mixture of mineral manures and ammonium salts or nitrate of soda, supplying only 86 lbs. of nitrogen per acre per annum. The fact is, that it is only the comparatively small proportion of the nitrogen of farm-yard manure which is due to the liquid dejections of the animals, that is in a readily and rapidly available condition; whilst that due to more or less digested matter passing in the fœces, is more slowly available, and that in the litter remains a very long time inactive. Hence, the addition of nitrogen as nitrate of soda to the farm-yard manure had a very marked effect.

TABLE II.

POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Manures and Produce per acre per annum; 12 years, 1876-1887.

	Good.		Small.		Diseased.		Total.		Per cent. Diseased in Total.
UNMANURED, 12 years. (Plot 1.)									
	Tons.	cwts.	Tons.	cwts	Tons.	cwts.	Tons.	cwts.	Per cent.
Averages: 6 years, 1876-1881	1	$17\frac{7}{8}$	0	$5\frac{5}{8}$	0	2	2	$5\frac{1}{2}$	4·27
Averages: 6 years, 1882-1887	1	9	0	$4\frac{1}{4}$	0	$0\frac{1}{2}$	1	$13\frac{3}{4}$	1·63
Averages: 12 years, 1876-1887	1	$13\frac{1}{2}$	0	5	0	$1\frac{1}{4}$	1	$19\frac{3}{4}$	3·15
FARM-YARD MANURE, 6 YEARS; UNMANURED, 6 YEARS. (Plot 2.)									
Averages: 6 years, 1876-1881	4	$11\frac{7}{8}$	0	7	0	$5\frac{3}{4}$	5	$4\frac{5}{8}$	5·54
Averages: 6 years, 1882-1887	2	$13\frac{1}{8}$	0	$6\frac{1}{8}$	0	$1\frac{3}{4}$	3	1	2·88
Averages: 12 years, 1876-1887	3	$12\frac{1}{2}$	0	$6\frac{1}{2}$	0	$3\frac{3}{4}$	4	$2\frac{3}{4}$	4·56
FARM-YARD MANURE AND SUPERPHOSPHATE, 7 YEARS; FARM-YARD MANURE ALONE, 5 YEARS. (Plot 3.)									
Averages: 6 years, 1876-1881	4	$16\frac{7}{8}$	0	$7\frac{1}{4}$	0	$7\frac{1}{2}$	5	$11\frac{5}{8}$	6·73
Averages: 6 years, 1882-1887	3	$17\frac{1}{2}$	0	$5\frac{3}{8}$	0	$2\frac{1}{4}$	4	$5\frac{1}{8}$	2·58
Averages: 12 years, 1876-1887	4	$7\frac{1}{8}$	0	$6\frac{3}{8}$	0	$4\frac{7}{8}$	4	$18\frac{3}{8}$	4·93
FARM-YARD MANURE, SUPERPHOSPHATE, AND NITRATE OF SODA, 6 YEARS; FARM-YARD MANURE ALONE, 6 YEARS. (Plot 4.) (*)									
Averages: 6 years, 1876-1881	5	$17\frac{3}{4}$	0	$6\frac{5}{8}$	0	$17\frac{7}{8}$	7	$2\frac{1}{4}$	12·56
Averages: 6 years, 1882-1887	3	13	0	$5\frac{1}{2}$	0	$1\frac{3}{4}$	4	$0\frac{1}{4}$	2·21
Averages: 12 years, 1876-1887	4	$15\frac{3}{8}$	0	$6\frac{1}{8}$	0	$9\frac{3}{4}$	5	$11\frac{1}{4}$	8·82
SUMMARY. AVERAGE 12 YEARS, 1876-1887.									
Unmanured	1	$13\frac{1}{2}$	0	5	0	$1\frac{1}{4}$	1	$19\frac{3}{4}$	3·15
Farm-yard Manure, 6 years; Unmanured, 6 years ..	3	$12\frac{1}{2}$	0	$6\frac{1}{2}$	0	$3\frac{3}{4}$	4	$2\frac{3}{4}$	4·56
Farm-yard Manure and Superphosphate, 7 years; Farm-yard Manure alone, 5 years	4	$7\frac{1}{8}$	0	$6\frac{3}{8}$	0	$4\frac{7}{8}$	4	$18\frac{3}{8}$	4·93
Farm-yard Manure, Superphosphate, and Nitrate Soda, 6 years; Farm-yard Manure alone, 6 years (*)	4	$15\frac{3}{8}$	0	$6\frac{1}{8}$	0	$9\frac{3}{4}$	5	$11\frac{1}{4}$	8·82

(*) The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

The next point to consider is the effects of the residue of the previously applied manures, as shown in the second line of each division of the Table.

The second division shows that, after the application of farm-yard manure, containing about 200 lbs. of nitrogen per acre, for six years in succession, there was, over the next six years without manure, a falling off in the annual average produce of tubers from nearly 5¼ to little over 3 tons;—that is, to less than the average produce obtained by artificial mineral manures without any nitrogen. There is here striking evidence of the very slow action of the large residue, mineral as well as nitrogenons, of the farm-yard manure.

The third division shows that with the cessation of the addition of superphosphate to the farm-yard manure, the crop was reduced from 5 tons 12 cwts. to 4 tons 5 cwts. It is true that the later seasons were less favourable for luxuriance. Still, the evidence points to the conclusion that the residue of the superphosphate had comparatively little effect; and that, in fact, it remained within the soil in a condition only slowly available.

Lastly, the fourth division shows that with the cessation of the application of the nitrate of soda, the average produce was reduced from 7 tons 2 cwts. to only 4 tons, or by more than 3 tons per acre per annum. Allowing for the difference in the character of the seasons, there would still appear to have been practically no immediately available residue of the nitrogen of the nitrate left within the root-range of the crop.

The fact that, over the last six years, farm-yard manure, together with the residue of previously applied farm-yard manure, superphosphate, and nitrate of soda, only yielded an average of about 4 tons of tubers; and that farm-yard manure and the residue of farm-yard manure and superphosphate, only gave about 4¼ tons, whilst farm-yard manure alone gave over the first six years 5¼ tons, is clear indication that the later seasons were somewhat less favourable for luxuriance with such manures.

As in the case of the artificial manures, so now with the farm-yard manure series, the last column of the Table shows a very much larger proportion of diseased tubers over the earlier than over the later years; and, consistently with the results with the artificial manures, there is the largest proportion where there was the largest supply of nitrogen; that is where nitrate of soda was added to the farm-yard manure. In comparing period with period, however, it must not be forgotten that the "Rock" was grown in the first four years, and the "Champion" afterwards.

The summary given at the foot of the Table shows the average results for each of the farm-yard manure plots, over the whole period of twelve years. The results have, of course, to be read with due reference to the changes in the manuring over the later years, and hence are not very direct in their indications.

It is somewhat remarkable that on neither plot with farm-yard manure, not even where it was applied each year of the twelve, was there so much produce as on the artificially manured plots receiving both mineral and nitrogenous manures. Indeed, not even where nitrate of soda was applied in addition to the farm-yard manure during the first six years, did the average produce of the twelve years amount to six tons of tubers.

The last column of the summary shows, as before, that the proportion of diseased tubers was the greater, the greater the amount of nitrogen supplied, and the greater the luxuriance.

Upon the whole it is obvious that, in the case of this somewhat agriculturally exhausted arable land, mineral manures alone had more effect than nitrogenous manures alone; but that, mineral constituents being adequately supplied, the further addition of nitrogenous manures was essential to obtain anything like full crops.

CONSTITUENTS IN THE CROPS PER ACRE PER ANNUM.

1.—*Artificial Manure Series.*

It will be of interest next to consider, what is the increased amount of some of the more important constituents of the tubers stored up in the crop, under the influence of the different manures; and especially what is the increased amount of them stored up, for a given quantity of nitrogen supplied in manure. Results of the analyses of the various crops, to which I shall call special attention when considering the percentage composition of the tubers, supply the data for estimates on these points.

Table III. (p. 10), gives the results for the artificially manured series.

The upper division of the Table shows the amounts, in lbs., of total dry or solid matter, of nitrogen, of total mineral matter (or ash), of potash, of phosphoric acid, of sulphuric acid, and of chlorine, in the average produce, per acre, per annum, over the twelve years, without manure, and with each of the six different artificial manures. These are the total quantities in the crops per acre; but the amount of seed Potatoes planted would, on the average, supply to the soil perhaps as much as one-third or more of the various constituents as were removed in the unmanured produce; and, of course, the same actual amounts, but a much less proportion of the whole in the produce, would be supplied in the case of the manured crops. It seems desirable, however, that the Table should give the actual amounts in the crops, rather than any mere estimates founded on uncertain data; especially as the figures in the remaining divisions of the Table, which relate to the increase of constituents in the crops under the influence of the different manures, would not be affected by any correction for the amounts supplied in the seed.

In the second division are given the increased amounts of each of the same constituents per acre in the average produce of each of the manured plots, over the amount in the unmanured produce.

The third division shows the amounts of the several constituents in the increase of produce over that without manure, for 100 of nitrogen supplied in manure.

In the fourth division are shown the actual amounts of increase of the constituents per acre by the nitrogenous and mineral manure together, over those by the mineral manure alone; and the fifth and last division shows these increased amounts over those by the mineral manure alone, calculated for 100 of nitrogen supplied in manure.

TABLE III.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Constituents per acre per annum in Total Tubers. Average of 12 years, 1876-1887.

	Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phosphoric Acid.	Sulphuric Acid.	Chlorine.
CONSTITUENTS PER ACRE PER ANNUM.							
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Unmanured	1250	14·9	37·4	20·8	5·51	3·25	1·99
Superphosphate.. ..	2203	20·5	87·9	50·8	11·28	4·97	4·13
Mixed Mineral Manure	2235	19·9	93·6	53·9	11·91	5·75	4·44
Ammonium Salts ..	1343	19·7	39·5	21·6	4·74	3·23	3·70
Nitrate of Soda.. ..	1558	23·0	44·1	23·1	5·59	3·15	1·83
Ammonium Salts and Mixed Mineral Manure	3857	48·1	153·7	88·3	16·80	8·30	11·02
Nitrate of Soda and Mixed Mineral Manure	3844	50·8	149·0	85·2	17·51	8·61	4·16
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER UNMANURED.							
Superphosphate.. ..	953	5·6	50·5	30·0	5·77	1·72	2·14
Mixed Mineral Manure	985	5·0	56·2	33·1	6·40	2·50	2·45
Ammonium Salts ..	93	4·8	2·1	0·8	−0·77	−0·02	1·71
Nitrate of Soda.. ..	308	8·1	6·7	2·3	0·08	−0·10	−0·16
Ammonium Salts and Mixed Mineral Manure	2607	33·2	116·3	67·5	11·29	5·05	9·03
Nitrate of Soda and Mixed Mineral Manure	2594	35·9	111·6	64·4	12·00	5·36	2·17
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER UNMANURED.							
Ammonium Salts ..	108	5·6	2·4	0·9	−0·90	−0·02	1·99
Nitrate of Soda.. ..	358	9·4	7·8	2·7	0·09	−0·12	−0·19
Ammonium Salts and Mixed Mineral Manure	3031	38·6	135·2	78·5	13·13	5·87	10·50
Nitrate of Soda and Mixed Mineral Manure	3016	41·7	129·8	74·9	13·95	6·23	2·52
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER MIXED MINERAL MANURE.							
Ammonium Salts and Mixed Mineral Manure	1622	28·2	60·1	34·4	4·89	2·55	6·58
Nitrate of Soda and Mixed Mineral Manure	1609	30·9	55·4	31·3	5·60	2·86	−0·28
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER MIXED MINERAL MANURE.							
Ammonium Salts and Mixed Mineral Manure	1886	32·8	69·9	40·0	5·69	2·97	7·65
Nitrate of Soda and Mixed Mineral Manure	1871	35·9	64·4	36·4	6·51	3·33	−0·33

Referring to the first division, it is seen that whilst without manure there is an average of only 1250 lbs., or little more than 11 cwts. of total dry or solid matter, produced per acre, there is not much more (1343 lbs.) with purely nitrogenous manure as ammonium salts, and scarcely one-fourth more (1558 lbs.) with the same amount of nitrogen as nitrate of soda. There is, on the other hand, with the purely mineral manures, nearly 20 cwts. (2203 and 2235 lbs.), and with the nitrogenous and mineral manures together an average of about 34½ cwts. (3857 and 3844 lbs.) of solid matter produced per acre per annum.

The average amount of nitrogen annually stored up in the tubers grown without manure was, notwithstanding the amount supplied in the seed, only 14·9 lbs.; or less than would be yielded in wheat or barley under similar circumstances. By mineral manures alone the amount was raised to about 20 lbs., or to nearly as much as in wheat or barley under the same conditions. On the other hand, the direct application of 86 lbs. of nitrogen, per acre per annum, when as ammonium salts alone, only raised the amount taken up to 19·7 lbs., and when as nitrate of soda alone, to only 23·0 lbs. The incapacity of the plant to avail itself of the supplied nitrogen in the absence of a sufficient available supply of mineral constituents, is here very strikingly illustrated. With the same applications of nitrogen, but in conjunction with the mixed mineral manure, the amount of nitrogen stored up in the tubers is raised from about 20 to about 50 lbs.;—48·1 lbs. with the ammonium salts, and 50·8 lbs. with the nitrate of soda.

The remaining columns of the upper division of the Table show that very little more of either the total, or the individual, mineral constituents, was taken up under the influence of the purely nitrogenous manures, than without manure. With the mineral manures alone, however, there was more than twice as much, both of total mineral constituents, and of the more important individual ones, taken up; and there was three or four times as much taken up when the nitrogenous and the mineral manures were used together. The figures relating to potash and phosphoric acid afford striking illustrations on these points.

The influence of the manures on the amounts of constituents taken up by the crop is, however, brought out more clearly still in the second division of the Table, which shows the amounts of each constituent stored up more than without manure.

It is seen that, whilst the purely nitrogenous manures have but little increased the production of solid matter, the mineral manures alone have increased it by nearly 1000 lbs. (953 and 985 lbs.) per acre, and the nitrogenous and mineral manures together have increased it by about 2600 lbs. (2607 and 2594 lbs.), or by more than 23 cwts. per acre.

It is remarkable that the purely nitrogenous manures, supplying 86 lbs. of nitrogen, have scarcely increased the assimilation of nitrogen more than the purely mineral manures; whilst the application of the two together has increased it very much—by 33·2 and 35·9 lbs. These latter amounts, when calculated for 100 nitrogen supplied in manure, as shown in the third division of the Table, represent a recovery in the increase of the crop of 38·6 and 41·7 per cent. of the nitrogen supplied in the manure. But when the increased assimilation of nitrogen is calculated, not over the amount in the unmanured produce, but over that in the produce by the mixed mineral manure alone, it represents, as shown in the bottom division, only 32·8 and 35·9 per cent. recovered.

These amounts of nitrogen recovered in the increased produce of Potatoes, for 100 supplied in manure, are less than were so recovered in Mangel Wurzel receiving similar manures. Thus the amount of nitrogen recovered for 100 supplied (with mineral manures) when as ammonium salts, was with Mangel Wurzel 42·3, against only 32·8 with Potatoes; and when the supply was as nitrate of soda, 59·9 per cent. of the nitrogen was recovered as increase in the Mangel Wurzel, against only 35·9 per cent. with the Potatoes. The proportion recovered in Potatoes is, however, approximately the same as in the case of Wheat, but less than that in the case of the spring sown Barley.

Referring in less detail to the amounts of other constituents taken up under the influence of the different manures, it is seen that by far the most prominent increase is in the potash, and second in order comes phosphoric acid. It is remarkable that, by the use of superphosphate of lime alone, 30 lbs. more potash are taken up per acre than without manure, and that only 3 lbs. more are taken up under the influence of the mixed mineral manure alone, which, besides superphosphate, supplied annually nearly 150 lbs. of potash. It is well known that one special effect of superphosphate of lime applied to spring sown crops, is greatly to increase the development of feeding-root within the surface soil; and here it would seem that under its influence, probably on both soil and plant, the Potato has been enabled to obtain a large amount of potash from the stores of the surface soil.

The purely nitrogenous manures, on the other hand, have not enabled the plant to take up an appreciably increased amount of potash.

It is, however, where the mineral and nitrogenous manures were applied together, that the greatest amount of potash is taken up. Indeed, under the influence of this combination, nearly one-half of the 150 lbs. of potash annually supplied is recovered in the increased produce, 67·5 lbs. in one case, and 64·4 lbs. in the other.

But little is definitely known of the special function of individual mineral constituents in vegetation. It is, however, pretty clearly established that the presence of potash is essential for the formation of the chief non-nitrogenous matters—starch and sugar. The published results of experiments at Rothamsted have shown that the proportion of potash in the ash of wheat was the greater, the better matured the grain—that is the larger the proportion of starch it contained; and here in the potato we find a greatly increased amount of potash in the heaviest crops, that is to say in those in which the largest amounts of starch have been formed.

The accumulation of phosphoric acid, on the other hand, is more directly connected with the assimilation of nitrogen, and the formation of the nitrogenous compounds. The amounts of phosphoric acid are seen to be much less than those of potash; but the differences in the amounts bear an obvious, though not a numerically direct, relation, to the differences in the amounts of nitrogen in the crops.

Sulphuric acid is also essential, as a supply of sulphur, to the formation of certain nitrogenous constituents of the plant. It is seen that the quantities are considerably less than those of phosphoric acid, and that the variations have some, but not a numerically direct connection with the amounts of nitrogen in the crops. It is to be borne in mind, however, that the methods of preparing ashes for analysis, do not in all cases secure the retention in them, as sulphuric acid, of the whole of the sulphur in the substance incinerated. On the other hand, the ashes, especially of other than such fixed products as ripened seeds, generally contain sulphuric acid existing as such in the crude product.

The amounts of the chlorine taken up by the plant are very variable, and have relation chiefly to the supplies by manure, and probably none to the formation of any organic compounds.

2.—*Farm-yard Manure Series.*

Let us now turn to the consideration of similar particulars relating to the farm-yard manure series of plots—that is to what may be called the chemical statistics of the crops.

Table IV. (p. 14) gives the results for the first and second periods of six years each, separately; also the difference between the two, or the results for the twelve years, as the case may be.

It is seen that, without manure, there is less of every constituent stored up in the crop over the second than over the first period of six years. This reduction of course represents exhaustion, as well as any influence of the seasons. In the case of each of the manured plots, the whole, or some item, of the manure, was omitted over the second period, so that some reduction in the yield would be anticipated; and it is seen that there was, under each condition of manuring, a reduction, and generally a very great reduction, in the amount stored up of every constituent, with the exception of the nitrogen in one case, as indicated by the + sign.

The upper division of the Table shows the actual quantities of the several constituents stored up per acre; but the significance of the facts will be better appreciated by an examination of the increased amounts over those without manure, as given in the second division of the Table.

It will be remembered that the quantity of farm-yard manure annually applied per acre was estimated to contain about 200 lbs. of nitrogen, besides a very large amount of mineral constituents. Yet, in no case was the increased yield of solid substance in the crop so great as was obtained by an artificial mixture of mineral and nitrogenous manure, supplying only 86 lbs. of nitrogen, but in a more readily available condition. Nor was the increased assimilation of any one of

TABLE IV.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Constituents per acre per annum in Total Tubers. 12 years, 1876-1887.

		Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phosphoric Acid.	Sulphuric Acid.	Chlorine.
CONSTITUENTS PER ACRE PER ANNUM.								
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Unmanured	6 yrs., 1876-81	1413	15·4	45·4	25·2	6·68	3·95	2·42
	6 yrs., 1882-87	1079	13·9	30·4	16·8	4·47	2·64	1·62
	Difference...	334	1·5	15·0	8·4	2·21	1·31	0·80
Farmyard Manure ...	6 yrs., 1876-81	3022	28·2	117·1	67·2	14·82	6·77	8·38
Unmanured	6 yrs., 1882-87	1944	24·3	58·8	33·8	7·45	3·40	4·21
	Difference...	1078	3·9	58·3	33·4	7·37	3·37	4·17
Farmyard Manure and Superphosphate	6 yrs., 1876-81	3188	29·0	130·0	74·7	15·61	7·61	10·27
Farmyard Manure alone	6 yrs., 1882-87	2512	33·6	91·6	52·6	10·92	5·36	7·23
	Difference...	676	+4·6	38·4	22·1	4·69	2·25	3·04
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	3886	48·7	148·1	83·7	17·95	9·00	6·92
Farmyard Manure alone	6 yrs., 1882-87	2327	33·4	84·5	47·7	10·24	5·14	3·95
	Difference...	1559	15·3	63·6	36·0	7·71	3·86	2·97
INCREASE OF CONSTITUENTS PER ACRE PER ANNUM OVER UNMANURED.								
Farmyard Manure ...	6 yrs., 1876-81	1609	12·8	71·7	42·0	8·14	2·82	5·96
Farmyard Manure—Residue	6 yrs., 1882-87	865	10·4	28·4	17·0	2·98	0·76	2·59
	Difference...	744	2·4	43·3	25·0	5·16	2·06	3·37
Farmyard Manure and Superphosphate	6 yrs., 1876-81	1775	13·6	84·6	49·5	8·83	3·66	7·85
Farmyard Manure and Residue.. ...	6 yrs., 1882-87	1433	19·7	61·2	35·8	6·45	2·72	5·61
	Difference...	342	+ 6·1	23·4	13·7	2·38	0·94	2·24
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	2473	33·3	102·7	58·5	11·27	5·05	4·50
Farmyard Manure and Residue.. ...	6 yrs., 1882-87	1248	19·5	54·1	30·9	5·77	2·50	2·33
	Difference...	1225	13·8	48·6	27·6	5·50	2·55	2·17
INCREASE OF CONSTITUENTS FOR 100 NITROGEN IN MANURE OVER UNMANURED.								
Farmyard Manure ...	6 yrs., 1876-81	805	6·4	35·9	21·0	4·07	1·41	2·98
Farmyard Manure—Residue	6 yrs., 1882-87	432	5·2	14·2	8·5	1·49	0·38	1·30
	12 years...	1237	11·6	50·1	29·5	5·56	1·79	4·28
Farmyard Manure and Superphosphate	6 yrs., 1876-81	888	6·8	42·3	24·8	4·42	1·83	3·92
Farmyard Manure, and Residue... ...	6 yrs., 1882-87	717	9·9	30·6	17·9	3·23	1·36	2·81
	12 years...	802	8·3	36·5	21·3	3·82	1·60	3·37
INCREASE OF CONSTITUENTS FOR 100 NITROGEN AS NITRATE, OVER FARMYARD MANURE AND SUPERPHOSPHATE.								
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	812	22·9	21·0	10·5	2·84	1·62	−3·90

the individual constituents, so great under the influence of the farm-yard manure, as when these were applied in the rapidly available condition as in the artificial mixtures.

It has been seen that, with the artificial manures, there was, of the nitrogen supplied, about 40 per cent. recovered in the increased crop (38·6 and 41·7) reckoned over the produce without manure, and about 34·5 per cent. (32·8 and 35·9) reckoned over the produce by purely mineral manures. But here, when the supply was in farm-yard manure, there was, as the third division of the Table shows, in one case only 6·4, and in another only 6·8 per cent. of the nitrogen so supplied, recovered in the immediate increase over the six years of the application; and, notwithstanding the great accumulation that would take place, there was only 8·3 per cent. recovered in the increase when the application was continued for 12 consecutive years.

It is further seen that after farm-yard manure had been applied for six years in succession, and it had yielded up to the crop only 6·4 per cent. of its nitrogen, over the next six years without manure, the large unrecovered residue only yielded 5·2 per cent. more; that is, only 11·6 per cent. in all, over the twelve years.

In the case of other crops it has been found that only a small proportion of the nitrogen of farm-yard manure was taken up in the year of the application. But these results seem to indicate that the Potato is able to avail itself of a less proportion of the nitrogen of the manure than any other farm crop. Yet, in ordinary practice, farm-yard manure is not only largely relied upon for Potatoes, but is often applied in larger quantity for them than for any other crop. It is probable that, independently of its liberal supply of all necessary constituents, its beneficial effects are in a considerable degree due to its influence on the mechanical condition of the soil, rendering it more porous and easily permeable to the surface roots, upon the development of which the success of the crop so much depends. Then, again, something may be due to an increased temperature of the surface soil engendered by the decomposition of so large an amount of organic matter within it; whilst the carbonic acid evolved in the decomposition will, with the aid of moisture, serve to render the mineral resources of the soil more soluble.

The Potato is, indeed, largely a kitchen and market garden crop, as well as a farm crop; and for the production of garden vegetables generally very large quantities of farm or stable manure are applied, beyond what is required as a mere supply of constituents to the crops—the process being to a great extent one of forcing, as above referred to; and a necessary result is a great accumulation of unexhausted residue within the soil.

It will be of interest to give here a few illustrations of the manuring and produce of potatoes, in some localities where they constitute an important item of production.

I will first refer to the evidence given before *The Select Committee on the Potato Crop.* The practice of several growers in Forfarshire is given. According to the various statements, the crop is generally grown in six, seven, or eight year rotation; and farm-yard, or stable manure, is largely relied upon; but it is frequently supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The quantity of dung used ranges from 12 to 14, and even to more than 20 tons per acre; and sometimes as much as 10 cwts. of artificial manure is also used, consisting chiefly of snperphosphate or dissolved bones, and potash salts, or kainit; and six tons is reckoned a fair crop. In East Lothian the crop is also grown in six, seven, or eight year rotation; as much as 30 tons of dung is used for the late crop, with 5 to 10 cwts. of artificials, consisting of guano or dissolved bones, and sometimes potash salts; and the crop is estimated at 6 to 8 tons per acre. For an early crop as much as 40 tons of dung, and 10 cwts. of a mixture of superphosphate, guano, and dissolved bones, are used, and only about 4 or 5 tons of produce is obtained. It was stated that, in Dublin County, potatoes are grown in four or five years course, with dung and artificials; the latter consisting of superphosphate, potash salts, and salts of ammonia or nitrate of soda; and 8 tons is considered a good crop. In Kent, one witness reports the growth of the crop once in five years, using 12 to 20 loads of farm-yard manure, with superphosphate, kainit, and sulphate of ammonia; and getting 10 to 11 tons of marketable tubers, and 2 tons of small. In another case in Kent 30 to 35 tons of dung are used.

Mr. T. H. Middleton, of Invergordon, Ross-shire, has kindly furnished me with further particulars as to the manuring and produce of potatoes in Scotland. He states that it is common to use 15 to 20 tons of farm-yard manure, with bone meal and superphosphate in addition. Or, sometimes, Potatoes are grown with artificial manure only; about 10 cwts., consisting of 3 cwts. superphosphate, 2 cwts. bone meal, 3 cwts. of kainit, and 2 cwts. sulphate of ammonia; and an average crop is about 6½ tons of Regents, or 7½ tons of Magnum Bonums. At a farm in Ayrshire, the practice for the growth of an early crop is to use 20 to 30 tons of dung, with 5 cwts. of kainit, and 8 or 10 cwts. of other artificial manures; consisting of good guano, or phosphatic guano with sulphate of ammonia, or any mixture containing 8 to 10 per cent. of ammonia, 20 to 30 per cent. of phosphate, and 3 to 5 per cent. of potash. In Forfarshire the crop is usually grown in an eight year course; 15 to 20 tons of farm-yard manure are used, with artificial manures in addition; 6 or 7 tons is reckoned an average crop, 10 tons a very good one, and 4 to 5 tons a bad crop. Sometimes, however, Potatoes are grown after three years grass, with artificial manures alone. In East and Mid Lothian, Potatoes are generally grown in a six year course; with about 20 tons of farm-yard manure, and artificial manures in addition. The description of the latter varies considerably; but the following is sometimes used:—2 cwts. ground bones, 1 cwt. vitriolized bones, 1½ cwt. mineral superphosphate, 1 cwt. sulphate of potash, and ½ cwt. sulphate of ammonia—in all 6 cwts. An average crop is 6 or 7 tons, and in very favourable seasons 10 or even 12 tons are obtained. Sometimes, however, in the Lothians, Potatoes are grown in six year course, after two years grass, and with artificial manure only, the farm-yard manure being reserved for the Turnips.

Such are typical cases of the manuring and produce of Potatoes when grown as a farm rotation crop. But it will be well to consider the conditions under which the crop is grown in a specially suitable climate for the early market. On this point I have been favoured with a very interesting account of Potato growing in Jersey, by Mr. F. Woodland Toms, the Official Analyst, of St. Heliers. The rents for suitable land are very high. No special rotation is followed. Potatoes are grown two or three years, then corn, then grass for a few years, and then Potatoes again. From 25 to 30 tons of farm-yard manure, or sea-weed, are applied per acre, with 8 to 12 cwts. of artificial manure, containing about 8 per cent. of ammonia, and 20 per cent. of soluble phosphate. Including rent, the total expenditure for the crop is often as much as £45 per acre, and sometimes even more; but almost always a second crop of some kind is taken the same year, after the removal of the Potatoes. The earliest crops, which command very high prices, average about 6 tons. But the average crop of the year ranges from 8 to 10 tons, according to season, with an average price of about £6 per ton. The price fluctuates, however, considerably, from season to season, and very much more throughout the season. Thus, it ranged, in 1886, from £10 per ton about the middle of June, to £3 11s. 6d. in the middle of August; in 1887, from £22 10s. at the end of May, to £6 11s. at the end of August; and in 1888, from £20 12s. 6d. at the beginning of June, to about £2 6s. in September and October.(*)

Lastly, Mr. C. B. Edwardes, of Peterborough, informs me that the market gardeners in the neighbourhood of Sandy, St. Neots, and Biggleswade, frequently apply from 30 to 60 tons of London stable manure per acre, for Potatoes, and even as much as 100 tons have, in some cases, been used. Frequently, too, besides the dung, ½ to 1 ton of artificial manure, or from 100 to 200 bushels of soot, are also used.

It will be seen that the foregoing statements of the actual practice in the growth of Potatoes, in different localities, are quite consistent with the experimental results that have been adduced, in showing how large is the amount of manure required in proportion to the amount of produce obtained.

INFLUENCE OF SEASON AND MANURING ON THE PERCENTAGE COMPOSITION OF THE TUBERS.

The next point to consider is the percentage composition of the Potato, and the direction, and the degree, in which this is influenced

(*) Since the above was in type, my attention has been called to Mr. W. E. Bear's article, entitled, *Glimpses of Farming in the Channel Islands*, in the last number of the Journal of the Royal Agricultural Society. He there gives a very interesting account of the farming in Jersey, and especially of the treatment and produce of the potato crop, and to this I would refer for further details on the subject.

TABLE V.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Mean percentage composition of the *Good* Tubers; 12 years, 1876-1887.

	Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.	
		Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.
Unmanured. (Plot 1.)						
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Averages: 4 years, 1876-1879	1·107	26·8	0·92	0·260	3·48	0·979
Averages: 4 years, 1880-1883	1·125	29·3	0·81	0·345	2·77	1·176
Averages: 4 years, 1884-1887	1·122	28·2	0·79	0·397	2·82	1·409
Averages: 12 years, 1876-1887	1·118	28·1	0·84	0·334	3·02	1·188
Superphosphate of Lime. (Plot 9.)						
Averages: 4 years, 1876-1879	1·102	24·4	1·13	0·197	4·64	0·805
Averages: 4 years, 1880-1883	1·122	28·2	1·06	0·226	3·76	0·806
Averages: 4 years, 1884-1887	1·121	27·8	1·02	0·325	3·67	1·165
Averages: 12 years, 1876-1887	1·115	26·8	1·07	0·249	4·02	0·925
Mixed Mineral Manure. (Plot 10.)						
Averages: 4 years, 1876-1879	1·102	24·2	1·15	0·189	4·74	0·782
Averages: 4 years, 1880-1883	1·121	28·0	1·09	0·222	3·89	0·794
Averages: 4 years, 1884-1887	1·118	27·3	1·09	0·297	4·00	1·090
Averages: 12 years, 1876-1887	1·114	26·5	1·11	0·236	4·21	0·888
Ammonium Salts = 86 lbs. Nitrogen. (Plot 5.)						
Averages: 4 years, 1876-1879	1·099	23·4	0·75	0·298	3·23	1·280
Averages: 4 years, 1880-1883	1·116	27·8	0·80	0·386	2·89	1·390
Averages: 4 years, 1884-1887	1·114	27·3	0·76	0·468	2·77	1·717
Averages: 12 years, 1876-1887	1·110	26·2	0·77	0·384	2·96	1·462
Nitrate of Soda = 86 lbs. Nitrogen. (Plot 6.)						
Averages: 4 years, 1876-1879	1·104	24·6	0·74	0·314	3·03	1·282
Averages: 4 years, 1880-1883	1·117	27·9	0·78	0·399	2·81	1·431
Averages: 4 years, 1884-1887	1·115	27·2	0·73	0·463	2·70	1·707
Averages: 12 years, 1876-1887	1·112	26·5	0·75	0·392	2·84	1·473
Ammonium Salts = 86 lbs. Nitrogen, and Mixed Mineral Manure. (Plot 7.)						
Averages: 4 years, 1876-1879	1·096	24·0	1·06	0·250	4·44	1·054
Averages: 4 years, 1880-1883	1·110	26·6	0·99	0·305	3·72	1·149
Averages: 4 years, 1884-1887	1·107	26·2	1·01	0·401	3·85	1·535
Averages: 12 years, 1876-1887	1·104	25·6	1·02	0·319	4·00	1·246
Nitrate of Soda = 86 lbs. Nitrogen, and Mixed Mineral Manure. (Plot 8.)						
Averages: 4 years, 1876-1879	1·100	24·4	1·06	0·265	4·37	1·096
Averages: 4 years, 1880-1883	1·115	26·6	0·97	0·339	3·70	1·273
Averages: 4 years, 1884-1887	1·110	26·3	0·95	0·419	3·62	1·602
Averages: 12 years, 1876-1887	1·108	25·8	1·00	0·341	3·90	1·324
Summary. Average 12 Years, 1876-1887.						
Unmanured	1·118	28·1	0·84	0·334	3·02	1·188
Superphosphate	1·115	26·8	1·07	0·249	4·02	0·925
Mixed Mineral Manure	1·114	26·5	1·11	0·236	4·21	0·888
Ammonium Salts alone	1·110	26·2	0·77	0·384	2·96	1·462
Nitrate Soda alone	1·112	26·5	0·75	0·392	2·84	1·473
Ammonium Salts and Mixed Mineral Manure ..	1·104	25·6	1·02	0·319	4·00	1·246
Nitrate Soda and Mixed Mineral Manure..	1·108	25·8	1·00	0·341	3·90	1·324

by season and manuring. Table V. (p. 18) illustrates these points for the artificial manure series, and Table VI. (p. 21) for the farm-yard manure series. For each separate period, and for the total periods of the experiments, the particulars given are—the average specific gravity of the tubers; the percentages of dry or solid matter, of mineral matter, and of nitrogen, in the fresh tubers, also the percentages of mineral matter, and of nitrogen, in the dry substance of the tubers.

1.—*Artificial Manure Series.*

Referring to the Table (V.), it is seen that not only without manure, but with each of the six descriptions of artificial manure, the tubers have a higher specific gravity over the second and third, than over the first period of four years. It will be remembered that during the second and third periods the Champion was grown instead of the Rock as previously, and also that the earlier seasons were upon the whole much wetter, and therefore more conducive to luxuriance and less to maturation.

In countries where the Potato is largely grown for the manufacture of starch or potato spirit, the specific gravity serves as an important indication of quality. The higher the specific gravity, the greater as a rule is the proportion of dry matter, and the greater the proportion of starch. Indeed, Tables are constructed for the calculation of the percentage of dry matter, and of starch, from the specific gravity of the tubers.

Consistently, the Table shows that, with the higher specific gravity of the tubers over the second and third periods, there was, in every case, a considerably higher percentage of dry or solid matter over those periods, indicating better maturation.

Another point usually coincident with relatively high maturity of produce, is a relatively low percentage of mineral, or ash-constituents; and the figures show, in the majority of cases, a lower percentage of mineral matter in the fresh tubers, and in every case a considerably lower percentage in the dry substance of the tubers, over the second and third periods, than over the first period.

A low percentage of mineral matter in the dry substance of a crop, especially in the case of ripened products such as grain, and corn generally, does not as a rule indicate a defective amount of mineral matter, but the greater formation of organic substance in proportion to the mineral matter taken up; by which, of course, the percentage of the mineral matter in the dry substance is reduced—in other words, there is more favourable maturation.

Thus, then, the results relating to specific gravity, and to the percentages of dry substance, and of mineral matter, are perfectly consistent with the known comparative characters of the produce of the different periods.

It is not so, at first sight, so far as the nitrogen is concerned. There is, in every case, a considerably higher percentage of nitrogen in the fresh tubers, and in every case but one a higher percentage in the dry substance of the tubers, over the second than over the first period, and in every case, both in the fresh and in the dry tubers, a higher percentage still over the third period.

Now in the case of the cereal grains, as a rule the better they are matured the lower is their percentage of nitrogen; the explanation being that maturation means the greater formation of the non-nitrogenous substance—starch—under the favourable ripening climatic conditions; and thus the already accumulated nitrogen shows a lower proportion to it, that is, a lower percentage. The same thing happens, though in a less marked degree, even in the case of the maturation of the succulent roots; the more there is of sugar accumulated, the lower is the percentage of nitrogen.

It will be seen further on that, in the case of the potato, more than 80 per cent. of the total nitrogen of the tuber exists in the juice, that is not in the fixed or insoluble portion. It is, in fact, in a very large proportion still formative or migratory matter. Hence, too, it is easy to understand how it is, as the results show to be the case, that the percentage of nitrogen in the tubers bears a very direct relation to the supplies available to the plant within the soil.

Leaving the figures relating to the separate periods, the summary at the foot of the Table gives the average results, as to specific gravity and percentage composition, over the total period of twelve years, for the unmanured plot, and for each of the artificially manured plots, and in these the influence of manure on the composition is more directly indicated.

Comparing the first and second columns with one another, it is seen at a glance that there is, with high specific gravity, high percentage of dry matter; and *vice versâ*. The produce without manure, and with purely mineral manure, that is to say with the least luxuriance, and consequently the earliest maturity, there is the highest specific gravity, and the highest percentage of dry substance in the tubers. With the nitrogenous manures alone, and very restricted growth, there is lower both specific gravity and percentage of dry matter; and, lastly, with both nitrogenous and mineral manures, and the greatest luxuriance, and imperfect maturity, there is the lowest specific gravity, and the lowest percentage of dry matter in the tubers.

Comparing one plot with another, the percentages of mineral matter and of nitrogen, whether reckoned on the fresh tubers, or on the dry substance, are seen to have no direct relation, either to the specific gravity, or to the percentages of dry matter, but to have a very direct relation to the supplies by manure; and when it is considered how large a proportion of both of these exists in the juice, or, so to speak, in a still formative and comparatively unfixed condition, the fact that their amount in the tubers bears so direct a relation to their supply becomes at once intelligible.

Thus, without manure, there is a comparatively low percentage of mineral matter, and a medium percentage of nitrogen. With mineral manures alone there is the highest percentage of mineral matter, and by far the lowest percentage of nitrogen. With purely nitrogenous manures there is the lowest percentage of mineral matter, and the highest percentage of nitrogen. Lastly, with both mineral and nitrogenous manures together, there are intermediate percentages, both of mineral matter and of nitrogen, in the tubers.

2.—*Farm-yard Manure Series.*

TABLE VI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Mean percentage Composition of the *Good* Tubers; 12 years, 1876-1887.

	Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.	
		Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.
UNMANURED, 12 YEARS. (Plot 1.)						
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Averages: 6 years, 1876-1881 ..	1·112	27·74	0·89	0·302	3·23	1·09
Averages: 6 years, 1882-1887 ..	1·123	28·44	0·80	0·366	2·81	1·29
Averages: 12 years, 1876-1887 ..	1·118	28·09	0·84	0·334	3·02	1·19
FARMYARD MANURE, 6 YEARS; UNMANURED, 6 YEARS. (Plot 2.)						
Averages: 6 years, 1876-1881 ..	1·106	25·78	1·00	0·241	3·91	0·93
Averages: 6 years, 1882-1887 ..	1·124	28·45	0·86	0·355	3·03	1·25
Averages: 12 years, 1876-1887 ..	1·115	27·11	0·93	0·298	3·47	1·09
FARMYARD MANURE AND SUPERPHOSPHATE, 7 YEARS; FARMYARD MANURE ALONE, 5 YEARS. (Plot 3.)						
Averages: 6 years, 1876-1881 ..	1·103	25·50	1·04	0·232	4·08	0·91
Averages: 6 years, 1882-1887 ..	1·112	26·36	0·96	0·353	3·66	1·35
Averages: 12 years, 1876-1887 ..	1·108	25·94	1·00	0·292	3·87	1·13
FARMYARD MANURE, SUPERPHOSPHATE, AND NITRATE OF SODA, 6 YEARS; FARMYARD MANURE ALONE, 6 YEARS. (Plot 4.) (*)						
Averages: 6 years, 1876-1881 ..	1·098	24·34	0·93	0·306	3·83	1·26
Averages: 6 years, 1882-1887 ..	1·110	25·89	0·94	0·372	3·64	1·44
Averages: 12 years, 1876-1887 ..	1·104	25·11	0·93	0·339	3·73	1·35
SUMMARY. AVERAGE 12 YEARS, 1876-1887.						
Unmanured..	1·118	28·09	0·84	0·334	3·02	1·19
Farmyard Manure, 6 years; Unmanured, 6 years ..	1·115	27·11	0·93	0·298	3·47	1·09
Farmyard Manure and Superphosphate, 7 years; Farmyard Manure alone, 5 years	1·108	25·94	1·00	0·292	3·87	1·13
Farmyard Manure, Superphosphate, and Nitrate Soda, 6 years; Farmyard Manure alone, 6 years (*) ..	1·104	25·11	0·93	0·339	3·73	1·35

* The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

Reference may be made more briefly to the specific gravity, and to the percentage composition, of the tubers of the farm-yard manure series, as recorded in Table VI. (p. 21).

The Table shows that there was in every case a higher specific gravity, in every case a higher percentage of dry matter, and in every case a lower percentage of mineral matter in the dry substance, over the second period than over the first. All three conditions indicate, therefore, better maturation over the later years.

The percentage of nitrogen is, on the other hand, in every case considerably higher over the second period, with, it will be remembered, lower amounts of crop, dependent partly on lower manuring, and partly on the conditions of season being on the average more favourable for maturation than for luxuriance. That the high percentage of nitrogen over the second period was due to deficient accumulation of starch, as the result of limitation of growth, and not to more total nitrogen being taken up, is obvious from the fact already shown, that there was, in two out of the three cases, less total nitrogen taken up per acre over the second period than over the first.

Owing to the difference in the manuring over the two periods, the average results for the twelve years, as given at the foot of the Table, are not of a very definite character; but they consistently show higher percentages of both mineral matter and of nitrogen, with relatively higher amounts supplied. Especially is the higher percentage of nitrogen very obvious in the produce of the plot to which nitrate of soda was applied during the first six years.

Upon the whole the results which have been given have consistently shown higher specific gravity, and higher percentages of dry matter, the better matured the produce. As between one set of seasons and another, they have also shown lower percentages of mineral matter in the produce of those of the best maturing conditions. But as between one condition of manuring and another, the percentages, both of mineral matter and of nitrogen, have been shown to have a very direct connection with the relative amounts of them supplied within the soil.

It was stated that this fact was no doubt connected with the further fact, that a very large proportion, both of the mineral constituents and of the nitrogen, of the tuber, exists in a still only formative condition in the juice.

Obviously, therefore, it will be of interest to consider such evidence as is at command, as to the comparative composition of the whole tubers, and of the juice, and as to the distribution of the several constituents in the insoluble matter, or so-called *marc*, and in the juice, respectively.

COMPOSITION OF THE WHOLE TUBERS, AND OF THE JUICE.

The upper division of Table VII. (p. 23) shows the percentages of dry matter, of mineral matter (both crude and pure ash), and of nitrogen, in the whole tubers, and in the expressed juice of the tubers, from each of the ten differently manured plots. The results are, in each case, the averages for the produce of the first three years—1876, 1877, and 1878.

TABLE VII.
EXPERIMENTS ON POTATOES,
Grown year after year on the same land, Hoosfield, Rothamsted.
Composition of the tubers, and of the juice.
Mixed year samples; Seasons, 1876, 1877, and 1878.

		Unmanured.	Superphosphate of Lime.	Mixed Mineral Manure. (*)	Ammonium Salts (= 86 lbs. Nitrogen).	Nitrate Soda (= 86 lbs. Nitrogen).	Ammonium Salts and Mixed Mineral Manure.	Nitrate Soda and Mixed Mineral Manure.	Farmyard Manure. Alone.	Farmyard Manure. And Superphosphate.	Farmyard Manure. Superphosphate and Nitrate Soda.	Means.
Percentage Composition of the Tubers and of the Juice.												
Dry Matter ...	Tubers	27·6	24·7	24·5	23·0	24·5	24·3	24·5	24·8	24·4	23·4	24·6
	Juice	4·6	4·7	4·6	4·7	4·9	4·8	5·1	4·5	4·6	4·9	4·7
Ash (Crude) ...	Tubers	0·91	1·14	1·14	0·75	0·73	1·10	1·07	1·01	1·05	0·95	0·99
	Juice	1·10	1·38	1·39	0·93	0·87	1·26	1·28	1·21	1·23	1·13	1·18
Ash (Pure) ...	Tubers	0·90	1·13	1·13	0·74	0·71	1·07	1·05	0·99	1·03	0·93	0·97
	Juice	1·08	1·37	1·38	0·93	0·87	1·26	1·27	1·21	1·22	1·12	1·17
Nitrogen ..	Tubers	0·27	0·19	0·18	0·31	0·32	0·25	0·26	0·22	0·20	0·29	0·25
	Juice	0·27	0·22	0·21	0·36	0·38	0·27	0·29	0·24	0·23	0·33	0·28
Percentage Composition of the Pure Ash.												
Ferric oxide and Alumina ...	Tubers	0·40	0·30	0·32	0·50	0·56	0·43	0·37	0·35	0·37	0·41	0·40
	Juice	0·50	0·53	0·51	0·44	0·49	0·37	0·51	0·51	0·46	0·56	0·49
Lime	Tubers	2·16	1·55	1·56	2·77	2·42	1·64	1·50	1·53	1·45	1·63	1·82
	Juice	2·27	1·67	1·94	2·26	2·27	1·81	1·75	1·67	1·56	1·74	1·89
Magnesia ...	Tubers	3·62	3·37	3·45	3·17	3·85	3·54	3·92	3·48	3·31	3·72	3·54
	Juice	4·32	3·76	3·80	3·55	4·17	3·86	4·42	3·91	3·67	4·16	3·96
Potash	Tubers	55·94	58·52	58·21	55·54	53·87	58·79	58·21	58·27	58·52	57·59	57·35
	Juice	53·42	57·92	57·08	55·53	54·02	56·89	57·31	56·81	57·39	56·00	56·24
Soda ..	Tubers	0·19	0·32	0·53	0·19	2·89	0·02	0·69	0·06	0·12	0·78	0·58
	Juice	1·77	0·37	0·57	0·49	2·00	0·49	0·74	0·52	0·49	1·21	0·87
Phosphoric Acid	Tubers	14·83	13·00	12·86	12·20	13·03	11·19	11·96	12·86	12·14	12·35	12·64
	Juice	11·12	10·87	10·27	9·33	10·21	8·90	9·46	10·11	9·35	9·73	9·93
Sulphuric Acid	Tubers	8·77	5·72	6·21	8·31	7·35	5·53	5·89	5·87	5·95	6·20	6·58
	Juice	9·99	6·91	7·23	9·54	8·86	6·78	7·45	6·91	6·72	7·07	7·75
Chlorine ...	Tubers	5·37	4·76	4·79	9·53	4·28	7·34	2·84	7·27	8·05	4·76	5·90
	Juice	5·42	5·43	5·60	11·65	6·35	7·46	3·22	8·73	9·08	5·36	6·83
Carbonic Acid...	Tubers	9·25	13·03	12·58	9·05	11·88	12·53	14·75	11·37	11·31	13·07	11·88
	Juice	12·16	13·63	14·17	9·67	12·90	15·02	15·77	12·69	13·23	15·27	13·45
Silica	Tubers	0·68	0·50	0·57	0·89	0·83	0·64	0·51	0·58	0·60	0·57	0·64
	Juice	0·25	0·13	0·09	0·16	0·16	0·11	0·09	0·11	0·10	0·11	0·13

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

The lower division of the Table shows the percentage composition of the pure ash, of the tubers, and of the juice, respectively; proportionally mixed samples of the ashes of the three years having been, in each case, made and analysed. The analyses were made by Mr. R. Richter, of Berlin.

The first three columns of the Table relate to the plots without nitrogenous manures—that is without any manure, with superphosphate alone, and with mixed mineral manure alone; the next four columns to the plots with artificial nitrogenous manures, without and with mineral manure in addition; and the last three to those with farm-yard manure.

It is seen in the upper division of the Table, that the percentage of dry substance in the tubers ranges from 27·6 per cent. in the unmanured produce, to only 23 per cent. with ammonium salts alone.

The percentage of dry matter in the expressed juice, ranges from 5·1 in that of the tubers grown by mixed mineral manure and nitrate of soda, and 4·9 in that of those by nitrate of soda alone, or nitrate of soda added to farm-yard manure—these being the conditions of the greatest luxuriance of growth—to 4·5 with farm-yard manure alone, 4·6 without manure, with the mixed mineral manure alone, and with farm-yard manure and superphosphate—these being conditions of comparatively early maturity. There is thus indication that the juice remains the richer the less matured the crop; in other words, that the juice includes a good deal of not finally fixed matter, which is, in fact, material for further maturation; or, like the starch itself, for the nutriment of the plant which would in natural course be grown from the tuber. It may here be stated that the juice, which shows the percentage composition recorded in the Table, generally constitutes not far from 80 per cent. of the fresh tubers.

Although the percentage of dry matter in the fresh juice ranges only about one-fifth as high as that in the fresh tubers, the lines recording the percentages of pure ash, uniformly show a higher percentage of it, that is of mineral matter, in the fresh juice than in the fresh tubers. This of course implies that there is a much lower percentage of mineral matter in the insoluble substance than in the juice. Indeed it will be seen further on that perhaps 85 per cent., or even more, of the total mineral constituents of the tubers, may exist in the juice. Then, again, there is a wide range of variation in the percentage of mineral matter, both in the fresh tubers, and in the fresh juice, according to the conditions of manuring; the variations in the case of the whole tubers being mainly due to those in the juice. We have in these facts further evidence of the less fixed condition of the constituents of the juice, and of the less essential occurrence of a considerable proportion of them.

Next as to the percentage of nitrogen: it is seen to range from 0·18 in the fresh tubers grown by mixed mineral manure alone, to nearly double, or 0·31 and 0·32 in those grown by nitrogenous manure alone. In the same cases it ranges in the fresh juice from 0·21 to 0·36 and 0·38; and when it is borne in mind that from 80 to 85 per cent. of the total nitrogen of the tubers may exist in the juice, it is obvious that the range of variation in its amount in the insoluble matter is comparatively limited. Further illustrations will be given on this point presently.

Referring to the lower division of the Table, the last column shows, for the ten different conditions as to manuring, the average percentage of each of the mineral constituents in the ash of the whole tubers, and in that of the juice. It is remarkable how nearly identical is the percentage composition of the two descriptions of ash, and this fact indicates much more of selective action, and of essentialness of composition, in the juice, than is generally found in the more purely vegetative organs of plants—such as the leaves and stems. But, in judging of the significance of the figures, it has to be borne in mind that the ash of the juice which shows this percentage composition may constitute 80 to 85 per cent., or even more, of the total ash of the tubers—a fact, the bearing of which will be illustrated further on.

I will not refer to much of the detail given in the other columns. It will suffice to call attention to the variations in the percentages of some of the more important constituents—potash and phosphoric acid for example—according to the conditions of manuring.

Thus it is seen that the percentage of potash ranges relatively high where the supply of it is relatively liberal, as for instance with the purely mineral manures, with the farm-yard manure, and with the nitrogenous and mixed mineral manures together. It is, on the other hand, relatively low without manure, and with the purely nitrogenous manures. Further, there is generally a somewhat corresponding tendency in the percentage in the ash of the juice, and in that of the whole tubers, a large proportion of the latter consisting of that of the former. Then it is to be observed, that where there was deficiency of potash in the supply, and in the ash, there is generally an increased percentage of lime in the ash, doubtless derived from the resources of the soil itself.

Next as to the phosphoric acid, its percentage is not so uniform as that of the potash. It is, under every condition of manuring, higher in the ash of the whole tuber than in that of the juice. On the other hand, the percentage of sulphuric acid is, in every case, higher in the ash of the juice than in that of the whole tubers. Lastly, in the ash both of the tubers and of the juice, when there is relatively high percentage of phosphoric acid, there is a general but not a uniform tendency to a relatively low percentage of sulphuric acid, and *vice versâ*.

Referring to the less essential constituents of the fixed formations, such as soda and chlorine for example, it may be observed that their percentage varies considerably, and is apparently very dependent on the supply within the soil.

CONDITIONS OF COMBINATION OF THE NITROGEN OF THE POTATO; AND THE DISTRIBUTION OF THE NITROGENOUS CONSTITUENTS IN THE SOLID MATTER, AND IN THE JUICE.

I now come to the very important question of the condition of combination of the nitrogen of potato tubers, and of the distribution of the nitrogenous compounds, in the solid matter, and in the juice.

Table VIII. (below) shows the proportion of the total nitrogen of the tubers which exists as albuminoid or flesh-forming compounds, and the proportion which is in other forms. It also shows the proportion of the albuminoids which exist in the insoluble condition in the marc, and in the soluble condition in the juice. The upper division of the Table gives some results of *E. Schulze*, and the lower division results obtained at Rothamsted, on these points.

TABLE VIII.

Proportion of Albuminoid Nitrogen, and Non-Albuminoid Nitrogen, in Potatoes.

	Per cent. of the Total Nitrogen of the Tubers—			
	Albuminoid.			Non-Albuminoid. (*)
	In Marc.	In Juice.	Total.	
E. SCHULZE'S RESULTS.				
	Per cent.	Per cent.	Per cent.	Per cent.
No. 1	19·8	41·0	60·8	39·2
No. 2	13·5	46·2	59·7	40·3
No. 3	20·0	27·4	47·4	52·6
No. 4	14·0	34·2	48·2	51·8
No. 5	24·2	40·8	65·0	35·0
Mean ..	18·3	37·9	56·2	43·8
ROTHAMSTED RESULTS, 1878.				
Unmanured	15·8	48·7	64·5	35·5
Superphosphate	9·1	57·6	66·7	33·3
Mixed Mineral Manure	14·4	57·5	71·9	28·1
Ammonium Salts	12·3	45·1	57·4	42·6
Nitrate of Soda	11·0	40·8	51·8	48·2
Ammonium Salts and Mixed Mineral Manure ..	16·1	47·6	63·7	36·3
Nitrate of Soda and Mixed Mineral Manure ..	17·1	46·9	64·0	36·0
Farmyard Manure	22·0	45·9	67·9	32·1
Farmyard Manure and Superphosphate	19·5	49·8	69·3	30·7
Farmyard Manure, Superphosphate, and Nitrate of Soda	12·6	46·5	59·1	40·9
Mean	15·0	48·6	63·6	36·4

(*) Chiefly Amide.

It is seen that, of the total nitrogen of the tubers, Schulze found the amount existing as albuminoids in the insoluble matter to range from 13·5 to nearly double, or 24·2 per cent. of the whole, and to average only 18·3 per cent. In other words, on the average of the five experiments, 81·7 per cent. of the total nitrogen of the tubers existed in the juice.

In the Rothamsted experiments there was probably much greater variation in the conditions and characters of growth, than in those of Schulze; and we find a variation in the amount of the total nitrogen of the tubers existing as albuminoids in the solid matter, from 9·1 to 22·0 per cent. of the whole; and the average to be only 15 per cent. The tendency of error of analysis would probably be to show too low an amount of the total nitrogen in the marc. However, the two sets of results sufficiently agree with one another to establish the fact that probably as a rule less than 20 per cent. of the total nitrogen will exist as insoluble albuminoids.

But the average of Schulze's results shows 37·9, and the average of the Rothamsted results 48·6 per cent. of the total nitrogen of the tubers, to exist as soluble albuminoids in the juice. In solid matter and juice together, therefore, Schulze's results show an average of 56·2 per cent., and those of Rothamsted of 63·6 per cent., of the total nitrogen of the tubers to exist as albuminoids; though from two-thirds to three-fourths of this may be in the juice.

On the other hand, Schulze's results show an average of 43·8, and those of Rothamsted of 36·4 per cent., of the total nitrogen of the tubers, to be in a non-albuminoid condition. By far the larger proportion of this non-albuminoid nitrogenous matter exists as amides, and much less as ammonia or nitric acid than is usual in the case of root-crops. The nutritive value of the non-albuminoid nitrogenous matters, which it is seen may amount to from one-third to perhaps nearly half of the total nitrogen of the tubers, is, however, to say the least, doubtful. Further, as two or three times as much of the albuminoid matter itself exists in the juice as in the insoluble portion of the tubers, it is probable that a considerable proportion, even of the albuminoid substance, will be lost as food. To this point I shall recur presently.

DISTRIBUTION OF THE CONSTITUENTS IN 1000 PARTS OF FRESH TUBERS.

It will be well now, disregarding the variations that may occur dependent on different conditions as to soil, season, manuring, and other circumstances, to endeavour to form a judgment as to the probable or approximate average composition of Potato tubers. Accordingly, Table IX. (p. 28) gives the estimated average composition of 1000 parts of fresh Potato tubers, and shows the probable distribution of the constituents, in the insoluble matter, and in the juice, respectively. The estimates are founded mainly on the average composition of the whole tubers, and of the juice, of the produce of the ten plots, over the first three seasons, 1876, 1877, and 1878, but partly also on other Rothamsted results, and on those of other experimenters.

The first column shows the estimated amounts of dry matter, nitrogen, total mineral matter (or ash), and of each ash-constituent, in 1000 of fresh tubers. The second and third columns show the distribution of the several constituents in the marc, and in the juice, respectively, of 1000 parts of the tubers.

The last two columns show, for 100 of dry matter, of nitrogen, and of ash, the proportion of each in the marc, and in the juice respectively.

They also show, for 100 of total ash in the tubers, the amount of each ash-constituent in the marc, and in the juice.

TABLE IX.

EXPERIMENTS ON POTATOES.

Hoosfield, Rothamsted.

Estimated average distribution of the constituents in 1000 parts of Fresh Tubers.

Constituents.	In Tubers.	In Marc.	In Juice.	Per cent. of total. In Marc.	Per cent. of total. In Juice.
Dry Matter	246	209	37	85·0	15·0
Nitrogen	2·5	0·4	2·1	15·0	85·0
Ash, Crude	9·9	1·5	8·4	15·0	85·0
Ash, Pure	9·7	1·4	8·3	15·0	85·0
Ferric oxide and Alumina	0·04	0·00	0·04	0·00	0·41
Lime	0·18	0·02	0·16	0·21	1·63
Magnesia	0·35	0·02	0·33	0·21	3·36
Potash	5·58	0·88	4·70	9·43	47·90
Soda	0·06	(−0·01)	0·07	(−0·11)	0·71
Phosphoric Acid	1·23	0·40	0·83	4·29	8·46
Sulphuric Acid	0·64	0·00	0·64	0·00	6·52
Chlorine	0·57	0·00	0·57	0·00	5·81
Carbonic Acid	1·16	0·04	1·12	0·43	11·42
Silica	0·06	0·05	0·01	0·54	0·10
Total	9·87	1·40	8·47	15·00	86·32
Deduct O = Cl.	0·13	0·00	0·13	0·00	1·32
Total	9·74	1·40	8·34	15·00	85·00

Directing attention first to the four upper lines of the Table, it is seen that 1000 parts of fresh Potato tubers are estimated to contain, on the average, 246 parts (or 24·6 per cent.) of total dry substance; 209 of which will be in the marc, and 37 in the juice. These amounts represent, as the last two columns of the Table show, 85 per cent. of the total solid matter to be in the marc, and 15 per cent. to be in the juice.

The amount and the distribution of the nitrogen is next shown. 1000 parts of the fresh tubers are estimated to contain 2·5 parts of nitrogen, or 0·25 per cent. Of this 2·5 parts, only 0·4 parts are estimated to be contained in the insoluble matter, and 2·1 parts in the juice. In other words, as the last two columns show, only about 15 per cent. of the total nitrogen of the tubers are supposed to be in the insoluble matter, and 85 per cent. in the juice.

The next two lines relate to the amount, and the distribution, of the mineral or ash constituents; the first of the two represents the amounts of crude ash as incinerated, and the second the amounts of pure ash, that is excluding any adventitious matter, such as sand and charcoal. As the individual mineral constituents are reckoned on the amount of pure ash, attention may be confined to the amount and distribution of it.

1000 parts of fresh tubers are estimated to contain 9·7 parts, or nearly 1 per cent. of pure ash. Of this, only 1·4 parts are supposed to be in the insoluble matter, and 8·3 parts in the juice—amounts corresponding to only 15 per cent. of the total pure ash in the insoluble matter, and 85 per cent. in the juice.

Thus, whilst of the total dry substance of the tubers 85 per cent. is reckoned to be in the insoluble matter, and only 15 per cent. in the juice; of the total nitrogen, and of the total mineral matter, only 15 per cent. is reckoned to be in the insoluble matter, and 85 per cent. in the juice.

Attention must now be briefly directed to the amount and the distribution of the individual mineral constituents in 1000 parts of the fresh tubers, as shown in the lower portion of the Table.

The ferric oxide and alumina are found in immaterial amount, and are probably mainly to be attributed to traces of adherent soil, not removed from the tubers in washing.

The lime, the soda, and the silica, are also in immaterial amounts, and the quantity of magnesia is also comparatively small. As already pointed out, the quantity of chlorine is very variable, and mainly dependent on the amount of the supply, whilst its occurrence is probably connected with its agency as a carrier of other constituents, rather than as an essential constituent in connection with any special function of the plant. Then there is the carbonic acid, which is probably in great part, the product of the destruction of organic acid in the incineration.

There remain the potash, the phosphoric acid, and, in a less degree, the sulphuric acid, as prominent mineral constituents of the tubers.

The Table shows that 1000 parts of the fresh tubers are reckoned to contain 5·58 parts of potash, 1·23 parts of phosphoric acid, and 0·64 parts of sulphuric acid.

It has been stated that potash is essentially connected with the formation of starch, and other non-nitrogenous matters, and phosphoric acid, and in some degree sulphuric acid, with that of the nitrogenous compounds. Yet we see that, of the 5·58 parts of potash in 1000 parts of tubers, only 0·88 parts exist in the marc, and 4·7 parts in the juice. A portion of that in the juice may, of course, be surplusage considered in relation to the transformations with which it is connected. But the fact that a much larger amount of the potash remains in the juice unassociated with the already formed and stored up starch, is of itself no evidence that it has not been of avail in the changes necessary to its formation; and the fact that the percentages of potash and phosphoric acid, and even of sulphuric acid, are so comparatively uniform in the ashes of the total tubers, and in those of the juice, and that they vary so little under such very various conditions of manuring, that is of their supply, would indicate that the amounts have some direct relation to the physiological changes within the organ, essential to its special formations.

Turning to the phosphoric acid, it is seen that of the 1·23 parts in

1000 of fresh tubers, 0·40 are reckoned to be in the marc, and 0·83 in the juice; or almost exactly one-third in the marc, and two-thirds in the juice. That there should be a considerable proportion of the whole of the phosphoric acid in the juice, seems quite consistent with the fact that so large a proportion of the albuminoid compounds exists in the juice. Indeed the average of Schulze's analyses shows almost exactly the same proportion of the total albuminoids to be in the juice—namely about two-thirds—as the estimates now under consideration show to be the case with the phosphoric acid.

Of the 0·64 parts of sulphuric acid in 1000 of fresh tubers, practically the whole is found in the juice.

The general conclusion to which these calculations as to the distribution of the various constituents of Potato tubers leads is—that from 80 to 85 per cent., or even more, of the total nitrogen of the tubers may be in the juice, and that about the same proportion of the total mineral matter also, may be in the juice. Further, that about the same proportion—80 to 85 per cent.—of the total potash, and about two-thirds of the total phosphoric acid, are in the juice. And when it is borne in mind that two-thirds, or more, of the nitrogen existing as albuminoids is in the juice, it is obvious that if the mode of cooking the Potato is such as to exclude the constituents of the juice from the final food product, there is considerable waste of nutritive matter; and that, indeed, the proportion of albuminoid matter in the food is exceedingly small. When Potatoes are used as a mere adjunct to an otherwise liberal diet, the general practice is to cut off the rind, and to put the peeled Potatoes into cold water, by which a large proportion of the soluble albuminoid matters must be washed out, before the temperature of the water becomes sufficiently high to coagulate and fix them. A very large proportion of the potash must also be washed out under such circumstances. When, however, potatoes constitute an important item in the diet, as in the rural districts of Ireland for example, it is usual to boil them in their skins—or, as is said, in their jackets. Under such circumstances, certainly a much larger proportion of the albuminoid matter will reach the stomachs of the consumers; and doubtless much more of the potash and phosphoric acid also. Still, it is obvious that a Potato diet must be very deficient in the proportion of nutritive nitrogenous compounds.

INCREASED PRODUCTION OF STARCH BY NITROGENOUS MANURES.

But although only about 15 per cent. of the total nitrogenous compounds of the tuber exists in the insoluble matter, and a very large proportion of the remainder—greater or less according to circumstances—is not available as flesh-forming material, yet Table IX. shows that 85 per cent. of the total dry or solid matter of the tuber may be in the insoluble matter or marc. The next question to consider is, therefore, of what does this consist? It has been incidentally stated that it consists chiefly of the non-nitrogenous substance—starch. It has further been stated that the amount of starch may approximately be estimated from the specific gravity of the tubers, or from their percentage of dry substance. It has also been assumed that the increased amount of dry matter grown, per acre, under the influence of nitrogenous manures, consisted mainly of this non-nitrogenous substance. These various points are illustrated by the figures in the following Table (X).

TABLE X.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Estimates of Increase of Starch produced by Nitrogen in Manure. Average of 10 years, 1876-1885.

(Approximate Estimates.)

	Specific gravity of Tubers.	Dry Matter.		Starch.					
					Per acre.			For 1 Nitrogen in Manure.	
		Per cent. in Tubers.	Per Acre.	Estimated per cent. in Tubers.	In Produce.	In increase over Unmanured.	In increase over Mixed Mineral Manure.	In increase over Unmanured.	In increase over Mixed Mineral Manure.
		p. c.	lbs.	p. c.	lbs.	lbs.	lbs.		
Unmanured	1·116	28·0	1353	23·2	1120				
Mixed Mineral Manure	1·113	26·2	2384	21·9	1988				
Ammonium Salts...	1·108	25·8	1419	21·4	1169	49		0·6	
Nitrate of Soda	1·111	26·2	1649	21·7	1362	242		2·8	
Mixed Mineral Manure and Ammonium Salts	1·103	25·3	4121	21·1	3436	2316	1448	26·9	16·8
Mixed Mineral Manure and Nitrate Soda	1·107	25·5	4069	21·2	3368	2248	1380	26·1	16·1

The Table shows, for the tubers grown without manure, and with the mixed mineral manure alone, with the nitrogenous manures alone, and the mixtures of mineral and nitrogenous manures, the average specific gravity over the ten years, 1876 to 1885, the average percentage of dry matter in the tubers, and total dry matter produced per acre. Next is shown the estimated percentage of starch in the tubers, calculated from the percentage of dry matter, by a factor arrived at by a consideration both of the rules of estimate of others, and of the results of calculations at Rothamsted, eliminating the other constituents.

As already fully illustrated, it is seen that high specific gravity of the tubers and high percentage of dry matter go together. The total amount of dry matter produced per acre, is considerably increased by the mineral manure alone, but very much more when the mineral and nitrogenous manures are used together. Thus, the produce of dry substance of tubers was, without manure 1353 lbs. per acre; with purely mineral manure 2384 lbs.; and with the mixture of the mineral and nitrogenous manures more than 4000 lbs. per acre.

The remaining columns show, the estimated percentage of starch in the tubers, the calculated total amounts of it per acre on the different plots, the increased amounts per acre over the amount without manure, under the influence of the nitrogenous manures, both when used alone, and in conjunction with the mineral manures; also the increased amounts over the produce with purely mineral manures, when both mineral and nitrogenous manures are used together. Finally, there is shown the increased amounts of starch produced by the use of 1 part of nitrogen in manure, reckoned both over the unmanured, and over the mineral manured produce.

It will be observed that the Potatoes are reckoned to contain on an average more than 21 per cent. of starch.

The produce of starch per acre is 1120 lbs. without manure, and 1988 or nearly 2000 lbs. with purely mineral manure—that is without nitrogen. The amount with purely nitrogenous manure is not so great as that with purely mineral manure. But with both nitrogenous and mineral manure, the quantity of starch is raised to an average of about 3400 lbs., or about 1½ ton per acre.

The increased amount of starch over that without manure, produced by nitrogenous manures alone, containing 86 lbs. of nitrogen, is very small; only 49 lbs. when as ammonium salts; and 242 lbs. when as nitrate of soda. When both nitrogenous and mineral manures are used together, the increased amount of starch produced is more than 1 ton per acre—2316 lbs. with ammonium salts, and 2248 lbs. with nitrate of soda; but the increased amounts reckoned over the produce by the purely mineral manure, are only about two-thirds as much as when reckoned over the unmanured yield—namely, 1448 and 1380 lbs.

The last two columns show the increased amount of starch obtained for 1 of nitrogen supplied in the manure.

With the purely nitrogenous manures there is practically no increase in the amount of starch produced. When the two descriptions of manure are used together, there is, for 1 of nitrogen in manure, 26·9 and 26·1 parts, increased produce of starch reckoned over the unmanured produce, and 16·8 and 16·1 parts reckoned over the produce by the mixed mineral manure alone.

Here, then, in the Potato, we have a great increase in the production of the non-nitrogenous constituent—*starch*, by the use of nitrogen in manure, just as in the root-crops we have a great increase in the produce of the non-nitrogenous constituent—*sugar*, by the use of nitrogenous manure. There is, however, under corresponding conditions as to manure, somewhat more sugar produced in Mangel Wurzel for 1 of nitrogen in manure, than of starch in the Potato. Thus, with similar mineral manures, and the same amounts of nitrogen supplied, we had, reckoned over the produce by the mineral manures alone, in Mangel Wurzel 19·0 parts of sugar for 1 of nitrogen as ammonium salts, against 16·8 parts of starch in the Potato; and for 1 of nitrogen as nitrate of soda, we had 22·1 parts of sugar produced in the Mangel Wurzel, and 16·1 parts of starch in the Potato.

In the sugar-beet, however, there was even much more sugar produced for 1 of nitrogen—namely, when as ammonium-salts 28·6 parts, and when as nitrate of soda 36·0 parts.

As then the root-crops are essentially sugar-yielding crops, so the Potato is essentially a starch-yielding crop; and it is seen that, provided the mineral constituents are not deficient, the produce of both sugar and starch is greatly increased by the amount of nitrogen available to the plant within the soil, whether derived from previous accumulations, or from direct nitrogenous manuring.

This result, the greatly increased production of non-nitrogenous substances, by the use of nitrogenous manures, is equally striking in the case of cereal crops. The most prominent effect of the use of nitrogenous manures to such crops, is the increased production of starch in the grain, and of cellulose in the straw. Indeed, it is chiefly for the increased production of the non-nitrogenous substances, starch, sugar, and cellulose, that our direct nitrogenous manures are used. And if we reckon, not the amount of nitrogen applied, but only the increased amount of it taken up by the growing vegetation, it is obvious that the amounts of non-nitrogenous substances produced for 1 of nitrogen so taken up, are very much greater than the estimates above referred to would indicate.

In my lecture last year, I showed how small was the proportion of the flesh-forming nitrogenous constituents, to the non-nitrogenous or specially respiratory and fat-forming constituents, in root-crops; and in the Potato the proportion is considerably smaller still. For whilst the percentage of total nitrogen is much the same in fresh Mangel Wurzel, or Swedish Turnips, as in fresh Potatoes, the fresh tuber contains twice, or more than twice, as much digestible non-nitrogenous matter as the roots. On the other hand, a larger proportion of the total nitrogen exists as albuminoid compounds in the Potatoes than in the root-crops.

CONDITIONS OF SEASON AND MANURING FAVOURING DISEASE.

Thus far I have treated of the conditions of growth, and of the composition, of Potato tubers; and it has been shown that both the growth and the composition are very characteristically influenced both by season and manuring, and, so far as manure is concerned, very specially by nitrogenous manures. Incidentally it has been shown that both the occurrence, and the development, of the disease are also very materially influenced by both season and manuring.

The well known fact that the characters of the season have much to do with the development of the disease was very conclusively borne out by the results adduced. It was seen that under every condition as to manuring, whether artificial or otherwise, there was, on the average, a very much larger proportion of diseased tubers over the first four, or generally wetter seasons, when moreover the "Rock" was grown, than over the subsequent seasons of, on the average, better maturing conditions, but when also the "Champion" was grown. It is not without interest to observe, that there was such a very great reduction in the amount of disease over the later periods of the continuous growth of the crop on the same land; conditions which might be considered unfavourable for healthy growth. It should be stated, however, that every year fresh seed was procured from a distance.

Then, again, so far as the influence of manuring is concerned, it was seen that the proportion of diseased tubers was the least where there was no supply of nitrogen by manure; that is where there was the least luxuriance, and the most restricted growth, and with this, the ripening tendency early developed. On the other hand, it was where there was liberal supply of nitrogen, and the most luxuriant growth, that there was by far the greatest proportion of diseased tubers.

It is not within my province, nor am I competent, to pass any judgment on either the admitted, or the disputed points relating to the identity, the morphological characters, and the mode of development, of the fungus. But the investigations carried on at Rothamsted do throw some light on the conditions, both without and within the plant, under which the development of the fungus is the most favoured, and on the results of its growth on the chemical composition of the tubers.

The fact that wet seasons favour the development of the disease would seem, independently of any influence favouring the migration of the spores, to be largely dependent on the condition of succulence and activity engendered in the juice; and the fact that there is much less disease with restricted growth, and early ripening, may simply mean that, under such conditions of the tuber, there is in the juice a restricted supply of food for the fungus. At any rate it is under the contrary conditions—those in which the juice is relatively rich in nitrogenous and mineral matters—that the development of the disease is the most pronounced. It has to be borne in mind that, in the experiments under consideration, the occurrence of the meteorological conditions favouring the development of the disease, finds the tubers of the different plots in very different conditions, not only as to richness of juice due to supply by manure, but, owing to these very conditions, in very different states as to maturity, that is as to fixity of composition, or susceptibility to change. The question arises, therefore, how far the tubers of restricted development, and greater maturity, would have shown more susceptibility to the disease if the adverse meteorological conditions had prevailed at an earlier stage of their growth; or how far, if they had occurred later, the more luxuriant tubers would have suffered less. However this may be, certain it is that, when the unsuitable weather comes, those tubers suffer most which have the richest juice, and the least fixity of composition.

CHEMICAL CHANGES IN THE TUBERS, INDUCED BY THE DISEASE.

I now come to the question—what are the changes which the development of the disease induces in the chemical composition of the tubers? We have only been able to devote attention to this subject in certain special and limited aspects, but the results which have been obtained are consistent and definite, so far as they go, and of considerable interest.

In the first place, the percentages of dry matter, mineral matter, and nitrogen, were determined in the good or well-grown tubers, in the small or imperfectly developed tubers, and in the diseased tubers, of most of the experimental plots, in each of the first three years of the experiments. The sugar was also determined by the polariscope, in the juice of the good and of the small Potatoes.

Next, in a considerable number of cases, the white and the dark portions of diseased Potatoes were carefully separated. Each of these was separately pressed, so as to obtain the juice, and the insoluble portion or marc, separately, for analysis. In the juice of each, the mineral matter and the nitrogen were determined. In all cases the sugar, by polariscope, was determined; and, in selected cases, the glucose already existing, and the total sugar in the juice, after conversion into glucose. Lastly, in the marc, both of the white and of the dark portions, the mineral matter, and in some cases the nitrogen, was determined.

The data were thus provided, in the first place for comparing the composition, in some important aspects, of the fully matured, of the immature, and of the diseased, whole tubers; also for the comparison of the composition of the insoluble portion, and of the juice, both of the white or incipiently diseased, and of the dark or fully diseased, portions of the diseased tubers.

Table XI. (p 36) shows the percentages of dry matter, mineral matter, and in many cases of nitrogen in the dry matter, of the good, the small, and the diseased whole tubers, from each of the ten differently manured plots, in each of the first three years of the experiments—1876, 1877, and 1878. It also shows, in each case, the percentage of sugar, as determined by the polariscope, in the juice of the good, and of the small Potatoes.

I do not propose to refer in detail to the results relating to the produce of individual plots, but only to call attention to the general and average character of the results.

Referring first to the percentages of dry matter, a glance at the columns shows that, in every case but one in 1876, in eight out of the ten cases in 1877, and in nine out of ten in 1878, there was a lower percentage of dry substance in the less developed small, than in the more matured, or so designated "good" tubers. Again, there was, over the three years, in every case but one, a considerably lower percentage of dry matter in the diseased than in either the good or the small Potatoes. This result must obviously be due either to acquisition of water, or to loss of dry or solid substance, under the influence of the disease.

The next columns, which show the percentages of mineral matter in the dry substance of the different descriptions of tuber, afford satisfactory evidence that there had been a considerable loss of solid organic substance.

TABLE XI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of the Good, Small, and Diseased Potatoes.

	Per cent. in Tubers.									Per cent. in Juice.	
	Dry Matter.			Mineral Matter in Dry.			Nitrogen in Dry.			Sugar by Polariscope.	
	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.
First Season, 1876.											
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Unmanured	23·87	23·65	20·22	3·53	3·49	4·27	1·126	1·113	1·268	0·60	0·76
Superphosphate	23·50	22·85	18·42	4·72	4·86	5·73	0·844	0·961	1·622	0·43	0·57
Mixed Mineral Manure (*)	22·89	21·28	20·73	4·64	4·94	5·21	0·744	0·962	0·988	0·43	0·59
Ammonium Salts	22·10	22·29	18·62	3·67	3·70	5·24	1·501	1·493	1·855	0·48	0·55
Nitrate of Soda	22·00	21·49	19·00	3·59	3·84	4·48	1·486	1·510	1·784	0·46	0·60
Ammonium Salts and Mixed Mineral Manure	20·87	19·49	18·02	4·71	5·01	5·86	1·274	1·510	1·803	0·52	0·57
Nitrate of Soda and Mixed Mineral Manure	21·89	20·47	19·36	4·46	4·76	5·39	1·332	1·573	1·593	0·48	0·58
Farmyard Manure	23·42	22·01	20·78	4·11	4·20	4·64	0·954	1·026	1·118	0·57	0·69
Farmyard Manure and Superphosphate ...	23·45	22·32	20·46	4·27	4·56	5·01	0·814	1·010	1·110	0·58	0·62
Farmyard Manure, Superphosphate, and Nitrate of Soda	21·23	20·64	17·91	3·92	4·12	5·24	1·390	1·497	1·722	0·40	0·53
Mean	22·52	21·65	19·35	4·16	4·35	5·11	1·147	1·266	1·486	0·50	0·61
Second Season, 1877.											
Unmanured	33·03	27·47	25·01	3·17	3·28	3·61	0·914			0·49	0·97
Superphosphate	26·53	25·76	23·54	4·44	4·68	5·11	0·764			0·27	0·54
Mixed Mineral Manure (*)	26·76	24·64	22·79	4·52	4·85	5·35	0·778			0·25	0·37
Ammonium Salts	21·99	25·72	22·62	3·07	3·18	3·74	1·276			0·61	0·89
Nitrate of Soda	25·86	26·80	22·30	2·85	3·00	3·56	1·164			0·63	0·80
Ammonium Salts and Mixed Mineral Manure	28·44	23·72	22·20	4·33	4·90	5·63	0·951			0·23	0·47
Nitrate of Soda and Mixed Mineral Manure	27·27	24·36	22·89	4·26	4·85	5·49	0·981			0·49	0·50
Farmyard Manure	26·49	24·45	21·39	4·00	4·22	5·33	0·800			0·33	0·62
Farmyard Manure and Superphosphate	25·96	24·35	20·50	4·26	4·49	5·90	0·799			0·30	0·55
Farmyard Manure, Superphosphate, and Nitrate of Soda	27·21	24·25	23·10	3·90	4·14	5·04	1·107			0·29	0·63
Mean	26·95	25·15	22·63	3·88	4·16	4·88	0·953			0·39	0·63
Third Season, 1878.											
Unmanured	25·96	24·25	21·62	3·26	3·93	4·43	0·878			1·82	1·92
Superphosphate	24·08	22·90	19·86	4·74	5·28	6·93	0·684			1·42	1·30
Mixed Mineral Manure (*)	23·68	22·76	20·58	4·90	5·36	6·37	0·706			1·44	1·23
Ammonium Salts	24·88	24·10	19·64	3·12	3·26	4·15	1·246			1·57	1·42
Nitrate of Soda	25·47	23·93	21·56	2·64	3·37	3·41	1·281			1·60	1·88
Ammonium Salts and Mixed Mineral Manure	23·55	20·93	19·11	4·57	5·25	6·25	0·946			1·27	1·00
Nitrate of Soda and Mixed Mineral Manure	24·42	21·69	20·44	4·41	5·45	5·93	0·935			1·25	1·17
Farmyard Manure	24·36	22·48	20·39	4·20	5·05	5·21	0·857			1·20	1·93
Farmyard Manure and Superphosphate	23·76	22·11	18·22	4·35	5·05	5·92	0·864			1·29	1·77
Farmyard Manure, Superphosphate, and Nitrate of Soda	21·86	22·22	18·78	4·45	5·12	5·30	1·229			1·23	1·50
Mean	24·20	22·74	20·02	4·06	4·71	5·39	0·963			1·41	1·51

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

Quite consistently with the illustrations which have been before adduced, there is, with one exception, a lower, and sometimes a considerably lower, percentage of mineral matter in the dry substance of the more matured "good" than in the less matured "small" tubers. But the point of special interest is, that there is in every case, in each year, a higher, and frequently a much higher, percentage of mineral matter in the dry substance of the diseased, than in that of the sound tubers.

Now, as the mineral matter is fixed, and not subject to loss or gain, it is obvious that its increased amount in relation to that of the dry substance means that there has been a loss of the organic substance of the tuber under the iufluence of the disease, by which the proportion of the mineral to the organic matter is necessarily increased. It is possible, however, that in some cases the percentage of mineral matter may be slightly too high, owing to the difficulty of thoroughly cleansing the diseased tubers from adherent soil.

The next question is—whether this loss of organic substance is chiefly of the nitrogenous, or of the non-nitrogenous, constituents of the tubers? The columns showing the percentages of nitrogen in the dry substance of the good, the small, and the diseased tubers, in the first season, 1876, afford evidence on this point. There is almost uniformly a lower percentage of nitrogen in the dry substance of the good than in that of the small tubers, and this again is quite consistent with what has gone before. But there is in every case a higher, and sometimes a much higher, percentage of nitrogen in the dry substance of the diseased than in that of the sound tubers. The conclusion is, that it is chiefly, if not exclusively, non-nitrogenous constituents that have been lost; the proportion of the nitrogenous to the non-nitrogenous constituents being thereby increased.

Before leaving Table XI., the average results given in the bottom line for each year may be quoted, in further illustration of the conclusions which have been drawn from a general view of the detailed figures.

Thus, in 1876, the average percentage of dry substance is, in the good tubers 22·52, and in the diseased tubers only 19·35; the average percentage of mineral matter in the dry substance is, in the good tubers 4·16, and in the diseased tubers 5·11. Thus there is, with the disease, a lower percentage of dry matter, and a higher percentage of mineral matter in the dry substance—the two results together showing that there has been a loss of organic substance. Then, again, the percentage of nitrogen in the dry substance is, in the good tubers 1·147, and in the diseased tubers 1·486, or higher in that of the diseased than of the good tubers.

In 1877, with a very different range of percentages with different characters of season, the average percentage of dry matter is, in the good tubers 26·95, and in the diseased tubers only 22·63; whilst in the dry substance itself the average percentage of mineral matter is, in the good tubers 3·88, and in the diseased tubers 4·88.

In 1878, with again a different season, the results are quite accordant. Thus, the average percentage of dry matter is, in the good tubers 24·2, and in the diseased tubers only 20·02; whilst the average percentage of mineral matter in the dry substance is, in the good tubers 4·06, and in the diseased tubers 5·39.

The evidence is, therefore, consistent and conclusive, that coincidently with the development of the disease, there is a considerable loss of organic substance, and that the loss is chiefly, if not exclusively, of non-nitrogenous matter.

The last columns of the Table show that there is a small but appreciable amount of sugar determinable by the polariscope in the juice of the tubers; but, that there is generally, and on the average, somewhat less in that of the more matured "good" than in that of the small tubers. Further, the difference is the greater in the tubers of 1877, the season of the highest maturation of the three. The indication is, therefore, that the percentage of sugar in the juice diminishes with maturation.

FURTHER EVIDENCE AS TO THE CHANGES INDUCED BY THE DISEASE.

Table XII. (p. 39) gives a comparative view of the composition of the white or only partially diseased, and of the dark or more fully diseased portions of the affected tubers. The first eight columns relate to the composition of the juice, and the last four to that of the marc; that is, the solid residue remaining after the expression of the juice. For the first season, 1876, the results are given for only three plots; but for 1877 and 1878, for each of the ten plots. The analytical results are, however, in some important respects, more complete for the few plots of the first year. It will be convenient to refer first to the more numerous but less complete results for 1877 and 1878.

First as to the composition of the juice of the white, and of the dark, or more completely diseased portion of the tubers. The first two columns do not show uniformly more, or uniformly less, mineral matter in the juice of the dark, than in that of the white portion, but on the average nearly identical amounts. The irregularities are probably partly due to adventitious soil-matter, as before referred to, and this would affect the determinations in the dark, or more diseased portions, more than in those of the white portions.

The third and fourth columns show, however, that there is always very much less nitrogen in the juice of the dark than in that of the white portion—indicating that nitrogen has been appropriated by the fungus in the course of its growth.

The sugar determined by the polariscope is, each year, very much higher in the juice of the white portion of the diseased tubers, than in the juice of sound tubers. Thus, in 1876, there was, in the juice of the sound tubers (see Table XI., p. 36) an average of only 0·50 per cent. of sugar by the polariscope, but in the juice of the white portion of the diseased tubers there was an average of 1·307 per cent. In 1877 there was an average in the juice of the good tubers of only 0·39 per cent., and in

TABLE XII.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of Diseased Potatoes.

	Per cent. in Fresh Juice.								Per cent. in Dry Marc.			
	Mineral Matter (Ash).		Nitrogen.		Sugar. By Polariscope.		Sugar. Total reckoned as Glucose.		Mineral Matter (Ash).		Nitrogen.	
	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.
FIRST SEASON, 1876.												
Ammonium Salts and Mixed Mineral Manure		1·639	0·262	0·191	1·455	0·00			1·60	1·89	0·434	1·718
Nitrate of Soda and Mixed Mineral Manure	(2·084)	1·114	0·331	0·163	1·067	0·00			0·70	2·08	0·352	1·727
Farmyard Manure and Superphosphate	1·887	1·542	0·249	0·161	1·400	0·233			0·73	1·72	0·269	1·393
Mean	1·986	1·432	0·281	0·172	1·307	0·078			1·01	1·90	0·352	1·613
SECOND SEASON, 1877.												
Unmanured...	1·152	1·238	0·253	0·126	1·74	0·75			0·586	1·361		
Superphosphate	1·644	1·856	0·181	0·139	1·25	0·40			0·832	1·524		
Mixed Mineral Manure (*)	1·648	1·793	0·171	0·103	1·04	0·19	1·786	(0·351)	0·900	2·011		
Ammonium Salts	1·065	1·172	0·302	0·170	1·04	0·82			0·868	1·168		
Nitrate of Soda		1·166	0·205	0·164		0·62			1·163	1·381		
Ammonium Salts and Mixed Mineral Manure	1·720	1·793	0·279	0·143	0·67	0·52			0·824	1·112		
Nitrate of Soda and Mixed Mineral Manure	1·658	1·612	0·279	0·148	1·05	0·42	1·893	0·539	0·995	1·258		
Farmyard Manure... ...	1·503	1·578	0·199	0·107	1·32	0·47			0·681	1·443		
Farmyard Manure and Superphosphate	1·520	1·419	0·209	0·098	0·83	0·34			0·673	1·221		
Farmyard Manure, Superphosphate, and Nitrate of Soda	1·485	1·485	0·238	0·153	1·25	0·39			0·912	1·217		
Mean	1·488	1·511	0·232	0·135	1·13	0·49	1·839	0·445	0·843	1·370		
THIRD SEASON, 1878.												
Unmanured...	0·997	0·972	0·205	0·100	3·34	0·84	3·571	1·923				
Superphosphate	1·321	1·154	0·164	0·083	2·77	0·67	3·952	1·493				
Mixed Mineral Manure (*)	1·347	1·233	0·143	0·069	2·62	0·55	3·774	1·497				
Ammonium Salts	0·821	0·848	0·290	0·146	3·67	0·93	4·566	2·016				
Nitrate of Soda	0·698	0·767	0·319	0·134	2·87	0·60	3·788	2·293				
Ammonium Salts and Mixed Mineral Manure	1·188	1·160	0·198	0·074	2·03	0·33	3·125	1·462				
Nitrate of Soda and Mixed Mineral Manure	0·806	1·213	0·211	0·097	2·14	0·85	3·205	2·336				
Farmyard Manure... ...	1·100	1·066	0·170	lost.	2·48	0·45	3·497	1·377				
Farmyard Manure and Superphosphate	1·132	1·088	0·171	0·076	2·45	0·65	(3·164)	lost.				
Farmyard Manure, Superphosphate, and Nitrate of Soda	1·092	1·088	0·259	0·124	2·57	0·60	3·704	1·497				
Mean	1·050	1·059	0·213	0·100	2·69	0·65	3·635	1·766				

(*) Sulphates of Potash, Soda, and Magnesia, and Superphosphate.

that of the white portion of the diseased Potatoes of 1·13 per cent. And, again, in 1878, there was in the juice of the good tubers an average of 1·41 against 2·69 per cent. in the juice of the white portion of the diseased tubers.

The next point to observe is, that the sugar is always very much less in the juice of the dark portion, that is after the growth of the fungus; and, in the few cases in which the total sugar was determined, the reduction in the amounts of it in the juice of the dark portion is very marked; in 1877 from 1·839 to 0·445, and in 1878 from 3·635 to 1·766 per cent.

The evidence clearly points to the conclusion that in the incipient stages of the disease starch is destroyed and sugar formed. This may either serve directly as nutriment to the fungus, in the growth of which carbonic acid is evolved; or the sugar may itself be decomposed, evolving carbonic acid and other products, and hence the loss of non-nitrogenous organic substance.

If we now turn to the composition of the marc of the white and of the dark portions, as shown in the results relating to 1876 and 1877, it is seen that, in every case, there is a very much higher percentage of mineral matter in the dry substance of the dark portion, showing that it had been appropriated by the fungus, of which the dark matter chiefly consists.

As already said, the results show, in every case, very much less nitrogen in the juice of the dark than in that of the white portion, the conclusion being that the fungus had appropriated it in its growth.

Thus, in 1876, the average percentage of nitrogen was, in the juice of the white portion 0·281, and in that of the dark portion 0·172; in 1877, it was in that of the white portion 0·232, and in that of the dark portion only 0·135; and in 1878, the average percentage was in the juice of the white portion 0·213, and in that of the dark portion only 0·10 per cent.

The more complete results, but for the three plots only, in 1876, conclusively show that the nitrogen lost by the juice had been so appropriated in the growth of the fungus. The figures show, in the first place, that there is an average of 1·986 per cent. of mineral matter in the juice of the white, and of only 1·432 per cent. in that of the dark portions, or very much less in the juice of the dark part; that is after the withdrawal for the growth of the fungus. Next as to the nitrogen in the juice:—there is an average of 0·281 per cent. in that of the white or incipiently diseased portion, and of only 0·172 per cent. in that of the dark or more completely diseased—that is, much less after the growth of the fungus. Lastly, as to the juice:—the percentage of sugar as indicated by the polariscope is 1·307 in that of the white, and only 0·078 per cent. in that of the dark part.

That the less amount of both mineral matter and nitrogen in the juice of the dark portion is due to their having been taken up in the growth of the fungus is still more directly and conclusively shown by the results relating to the solid residue, or marc, remaining after the expression of the juice—the solid residue of the dark part consisting largely of the fungus itself.

Thus, whilst the average percentage of mineral matter in the marc of the white portion is only 1·01, or not very different from that in the dry substance of the sound tuber, the percentage in the marc of the dark portion is 1·90 or nearly double; and, again, whilst the percentage of nitrogen in the dry solid matter of the white portion is only 0·352, in that of the dark portion it is 1·613, or several times more. It is thus clearly shown, therefore, that the nitrogen lost by the juice has been appropriated in the growth of the fungus.

To sum up the evidence as to the changes suffered by the tuber under the influence of the disease, it would seem that the first material change is the destruction of starch, and the formation of sugar, apparently partly cane sugar and partly glucose. There is a considerable loss of organic, and chiefly non-nitrogenous, substance. This may be due in part to the decomposition of the produced sugar, and the evolution of carbonic acid and other products. But, it is, perhaps, mainly due to the evolution of carbonic acid, as a coincident of the growth of the fungus deriving its nutriment from ready-formed organic substance; this being a characteristic action in the growth of these non-chlorophyllous plants.

Finally, as the disease progresses, a very large proportion of both the mineral matter and the nitrogenous substance of the tuber is accumulated in the fungus. This is more especially the case in regard to the nitrogen, and in this fact we have doubtless some explanation of the further fact to which I have prominently called attention—namely, that the disease develops much more in tubers grown by highly nitrogenous manures, and having a highly nitrogenous juice, than in those grown under contrary conditions.

I have thus directed attention to the facts which the investigation has brought to light, as to the conditions, both of season and manuring, under which the disease is more or less developed, and also those as to the changes which take place in the composition of the tubers under the influence of the disease. It will, perhaps, be thought that I have stopped short of the point of most practical interest—namely, the suggestion of means of prevention of the disease. I do not propose to offer any specific recommendations on this point. At the same time, I think it will be granted, that any contribution to a clearer understanding of the conditions, and of the result, must lead to a better understanding of the cause, and that this, in its turn, is at any rate an essential step towards means of mitigation or prevention.

SUMMARY.

I have now discussed, in considerable detail, the conditions, both of season and manuring, upon which the successful growth of the Potato depends, and the results may be very briefly summarised as follows. Although of course requiring a full available supply of the mineral constituents within the soil, it has been seen that, these conditions being provided, the amount of produce is largely dependent on the available supply of nitrogen within the soil. In practice farm-yard manure is mainly relied upon. It is used in very large quantities per acre, and is sometimes supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The crop removes, however, a less proportion of the nitrogen of farm-yard manure than any other farm crop. It was seen that the most characteristic result of the increased growth under the influence of nitrogenous manures, was an increased production of the non-nitrogenous constituent—*starch.* It was shown, however, that for 1 of nitrogen supplied in manure, the increased amount of starch obtained in the Potato was less than the increased amount of sugar obtained in the Mangel Wurzel, and much less than that yielded in sugar-beet. It was further shown that although a larger proportion of the total nitrogen of the Potato is in the albuminoid condition than in the case of root-crops, yet from four-fifths to five-sixths, or even more, of the total nitrogen, and from two-thirds to three-fourths, or more, of the total albuminoids, of the tuber, may exist in the soluble condition in the juice; and it is obvious that in the usual mode of cooking the Potato for the table, most of this is lost as food.

Next it was shown that the disease, though largely dependent on season, developed much more in tubers grown by highly nitrogenous manures, and containing a juice rich in nitrogen, than under contrary conditions. Finally, it has been shown that a result of the disease is a destruction of starch, the formation of sugar, the loss of organic substance, and the growth of the fungus at the expense of the substance of the tuber.

YIELD OF POTATOES IN DIFFERENT COUNTRIES.

I propose, in conclusion, to call attention to such information as is available, as to the area devoted to the Potato, and the amount of the crop obtained, in the different divisions of the United Kingdom, and in a number of Foreign Countries.

Table XIII. (p. 43) gives the estimates, according to the "Agricultural Returns," of the area under the crop, the aggregate produce, and the average produce per acre, in 1884, 1885, 1886, and 1887, and the mean for the four years, for England and Wales, for Scotland, and for Ireland; also for Great Britain as a whole, and for the United Kingdom as a whole.

The figures show, that the area under the crop averaged over the four years, in England and Wales nearly 404,000 acres, and in Scotland about 153,000 acres, or not much less than two-fifths the area of England and Wales together. Over the same period, the average aggregate produce per annum was, in England and Wales rather over

2½ million tons, and in Scotland about 900,000 tons; or rather more than one-third as much as England and Wales, and over one-fourth of the total of Great Britain. It is further seen that, in Great Britain as a whole, the average area under the crop is about 557,000 acres, and the average aggregate produce rather more than 3,400,000 tons.

TABLE XIII.

POTATOES.

Area under the crop, aggregate produce, and produce per acre, in the United Kingdom.
Four seasons, 1884 to 1887 inclusive.

	1884.	1885.	1886.	1887.	Average.
Area under the Crop.					
	Acres.	Acres.	Acres.	Acres.	Acres.
England ... ... Wales ... ... (together)	401,201				403,758
England		359,026	363,782	369,243	
Wales		40,711	40,499	40,570	
Scotland	163,847	148,994	149,680	149,839	153,090
Great Britain ...	565,048	548,731	553,961	559,652	556,848
Ireland	798,952	797,292	799,847	796,939	798,258
United Kingdom ...	1,364,000	1,346,023	1,353,808	1,356,591	1,355,106
Estimated Aggregate Produce.					
	Tons.	Tons.	Tons.	Tons.	Tons.
England ... . Wales ... ... (together)	2,756,395				2,515,159
England		2,182,712	2,111,862	2,300,338	
Wales		212,269	214,791	282,268	
Scotland	986,808	803,523	841,110	982,288	903,432
Great Britain ...	3,743,203	3,198,504	3,167,763	3,564,894	3,418,591
Ireland	3,040,352	3,175,738	2,667,724	3,569,402	3,113,304
United Kingdom ...	6,783,555	6,374,242	5,835,487	7,134,296	6,531,895
Estimated Average Yield per Acre.					
	Tons.	Tons.	Tons.	Tons.	Tons.
England ... ... Wales ... ... (together)	6·87				6·23
England		6·08	5·81	6·23	
Wales		5·21	5·30	6·96	
Scotland	6·02	5·39	5·62	6·56	5·90
Great Britain ...	6·62	5·83	5·72	6·37	6·14
Ireland	3·81	3·98	3·34	4·48	3·90
United Kingdom ...	4·97	4·74	4·31	5·26	4·82

Ireland is seen to have an average area of nearly 800,000 acres under the crop, or not far from one-and-a-half time as much as Great Britain; whilst its aggregate produce is notably less than that of Great Britain.

The aggregate area under Potatoes in the United Kingdom is rather over 1⅓ million acres, and the aggregate produce is rather more than 6½ million tons of tubers.

Turning now to the average produce per acre, the lower division of the table shows, that England and Wales together are estimated to yield about 6¼ tons; Wales apparently yielding rather less than England. The average yield of Scotland is rather less than 6 tons per acre. These together give about 6⅛ tons as the average yield of tubers per acre per annum in Great Britain.

For Ireland the estimates show an average yield per acre of less than 4 tons, against more than 6 tons in Great Britain. It may be mentioned that the yield per acre given for Ireland, where the Potato is still of great importance as a supply of food for the people, is less than twice as much as was obtained at Rothamsted, over twelve years in succession on the same land, without any manure; it is scarcely more than was obtained by mineral manure alone; and considerably less than two-thirds as much as was yielded by mineral and nitrogenous manures together. It is clear, therefore, that the condition of the land, the cultivation, and the treatment of the crop, are, in Ireland, much inferior to those in the rest of the United Kingdom.

Table XIV. (below) gives similar particulars for 13 foreign countries, arranged in the order of their highest average produce per acre. Wherever the records were available, the averages for five recent years are given; and in other cases the best data at command have been taken. In all cases, however, the Table shows for what years the averages are calculated.

TABLE XIV.

POTATOES.

Area under the Crop, Aggregate Produce, and Produce per acre, in different countries.

	Number of years.	Seasons.	Average area under the Crop.	Estimated Aggregate produce.	Average yield per acre.
			Acres.	Tons.	Tons.
Norway	3	1865, '70, '75	80,417	482,233 (+)	6·01
Belgium	6	1878-'83	492,412 (*)	2,794,497 (‡)	4·54
Holland	5	1880-'84	350,284	1,434,358 (+)	4·09
Italy	6	1875-'80	169,210	693,042	4·09
Australasia	5	1880-'84	97,877	370,649	3·81
Germany	5	1882-'86	7,119,291	23,633,011	3·31
Sweden	5	1881-'85	381,616	1,224,646 (+)	3·21
Russia in Europe	5	1883-'87	3,172,935 (§)	6,713,187 (+)	2·93 (‖)
France	5	1880-'84	3,321,830	9,299,499 (+)	2·80
Austria	5	1881-'85	2,570,082	7,102,672 (+)	2·76
Hungary	5	1882-'86	1,006,147	2,618,321 (+)	2·62
Denmark	7	1881-'87	110,306 (§)	316,547 (+)	2·59 (§)
United States	5	1881-'85	2,197,877	4,139,313 (+)	1·87

(*) 1880 only. (+) Recorded in bushels, reduced to tons, reckoning 56 lbs. per bushel.
(‡) Average of seven years, 1880-'86. (§) 1881 only. (‖) 1872 only.

A glance at the Table shows that, as a rule, it is the countries of small area under the crop, and generally those of small total area, that stand at the head of the list, and show the highest yield per acre. Of these, Norway stands first, with an average of about 6 tons per acre, or rather less than Great Britain. Belgium comes next with an average of little more than 4½ tons, or about three-fourths as much as Great Britain. Then come Holland and Italy, with little over 4 tons per acre, or scarcely two-thirds as much as Great Britain.

Turning now to some of the larger countries, with larger areas under the crop, it is seen that Germany, where the Potato is much grown as an industrial crop, has an area devoted to it about thirteen times as large as in Great Britain, and yields about seven times the aggregate crop. But its average yield per acre is only 3·31 tons, or little more than half as much as that of Great Britain.

Then there is France, which, compared with Great Britain, has about six times the area under the crop, but yields less than three times as much aggregate produce, and gives considerably less than 3 tons per acre; that is, less than half as much per acre, as Great Britain, and even considerably less than Ireland.

Russia in Europe, again, according to the data, which are, however, incomplete and discordant, has, compared with Great Britain, nearly six times the aggregate area under the crop, but yields scarcely twice the aggregate produce; and, like France, yields less than 3 tons per acre; that is less than half as much as Great Britain.

Lastly, the United States, with nearly four times the area under the crop, but only about 1¼ time as much aggregate produce as Great Britain, yields an average of less than 2 tons per acre, or less than one-third as much as Great Britain.

Here, then, of 13 countries where the Potato is largely grown, their aggregate area under the crop being about 21 million acres, and their aggregate produce about 61 million tons, there is not one that reaches the average produce, per acre, of Great Britain. Norway, Belgium, and Holland, the most nearly approach our yield; and it is of interest to observe that these, and Denmark, are the countries that most nearly approach the United Kingdom in yield per acre of wheat and barley also.

It is, then, only the countries of small total area, and of small area under the crop, that at all nearly equal us in yield per acre; and among them, Belgium and Holland, the second and third on the entire list, more nearly approach us than any other, in *density of population*, and in *the amount of live-stock kept per acre*, and consequently in the supply of *manure*. Both these countries, too, have good home markets, besides their exports of agricultural produce.

It will be said, perhaps, that the better yield of potatoes per acre in Belgium than in most of the other countries, is due to the prevalence of peasant proprietors and small holdings; but, if this be so, how is it that it still yields only about three-fourths as much as Great Britain? Then, again, Germany yields per acre, little more than half as much potatoes, and only about two-thirds as much of either wheat or barley—and France less than half as much potatoes, and less than three-fifths as much wheat or barley—as Great Britain.

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