[CONTRIBUTION FROM THE BUREAU OF CHEMISTRY, U. S. DEPARTMENT OF AGRICULTURE, NO. 42.]

A STUDY OF THE AVAILABLE MINERAL PLANT FOOD IN SOILS.

BY C. C. MOORE.

Received November 28, 1901.

IN a study of soils, it is most essential, to have as wide a variety of types as possible, as at best, the study must be a comparative one. An hypothesis is taken and applied to the maximum number of types, concordant results classified, and the cause of the variations studied. The hypothesis is then amended, after which the work must be repeated according to the revised conditions. If such a study has been systematically carried out, and the variations have been reduced to the limit of error involved in a practical application of the same, then the hypothesis becomes a theory, which is stronger according to the number of types to which it may be successfully subjected.

In the conditions of organic work in nature, there are to be considered, what is the result, and how has that result been obtained? And that these problems are independent, one of the other, is of special significance in the presentation of this paper.

In the formation of a soil, using the word soil, in an agricultural sense, the practical interest is, to what degree of perfection has the work been done? That is, what state of fertility has the soil reached? The fertility of a soil is indicated by vegetation, if climatic conditions can be eliminated. To imitate the results obtained by vegetation, and condense the period of work from months to hours, means to forecast the amount of ingredients which go to make up a crop, which means the opportunity for supplying those ingredients, which would otherwise have been found deficient by the crop. And as such an imitation must necessarily be under purely arbitrary conditions, why should we feel called upon to use a single principle found in nature, other than those which suggest themselves on account of their simplicity.

The simple fact is presented, that a certain species of vegetation has accomplished a definite result, upon a specified type of soil. That the soil has given to the vegetation that amount of mineral matter, which was in a condition to be attacked and assimilated by the solvent and absorbent properties of the plant. And to estimate the amount of mineral matter which is in such a condition is to forecast the results of vegetation, always barring climatic conditions.

The fact that a crop did take up phosphorus pentoxide to the extent of 20 pounds per acre, is the very best of evidence that at least that much was available for the crop. Just how the crop accomplished the result, and what the long list of chemical reactions are, is at most but of secondary interest.

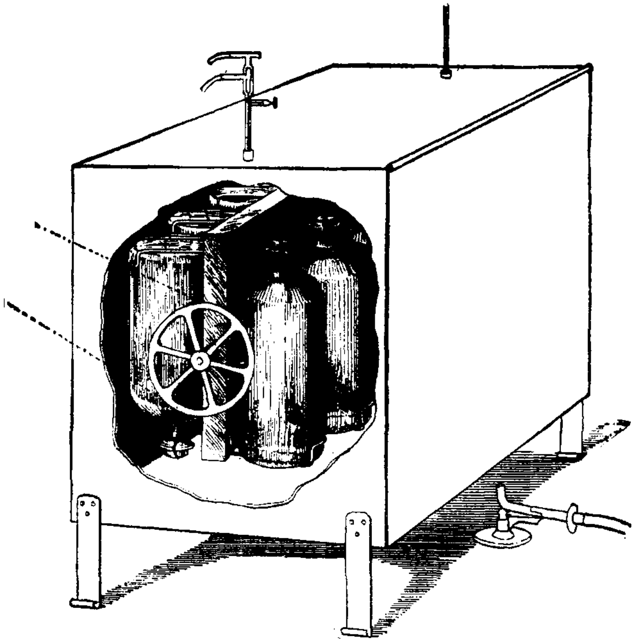
It is most apparent that the premise in such a line of reasoning is dependent upon the accuracy with which the vegetation indicates the degree of fertility. The growth of a crop is dependent upon the fertility of the soil and climate. In order to study one, the other must be eliminated. The only way to eliminate climatic conditions, is by culture in pots where the moisture and temperature are controlled. By the use of pots, any number of soils may be subjected to the same artificially perfect climatic conditions, which is to eliminate such conditions.

The series of pot experiments, which have been conducted by the department of agriculture for the past five years, has been noticed by most of those in this country, interested in such work. There are 175 pots in use, filled with virgin and cultivated soils and subsoils, including muck soils from Florida. The cropping has consisted of oats and beans, in duplicate pots, thus subjecting each type of soil to cereal and leguminous cropping. Each crop is always followed by buckwheat as a second crop, the same season, the same condition existing every year. A description of the pot culture, together with a detailed description of the methods that have been used in the planting, watering, harvesting, etc., has been prepared by Dr. Wiley, the head of this bureau, and is shortly to appear as the introduction to a bulletin on soil study. Awaiting this, the writer will not make reference to the cropping in detail, and upon which the accuracy of this paper is based.

It is proper to state that the work was originated by Dr. Wiley, who collected the samples with much judgment, and subsequently entrusted the line of research pertaining to the mineral food, and the compilation of such data, to the writer, who, with the exception of the nitrogen determinations, accepts a personal responsibility for the analytical work here presented.

To work backward, is many times the simpler method. If we have unquestionable results which were obtained by a crop, and a sample of the soil which was taken just previous to the planting, we have a definite result for which to work. If it is given what amount of mineral matter must be dissolved from a given amount of soil it is possible to vary the arbitrary conditions, until the desired result is obtained. And the more simple and elastic are the conditions made, with greater ease and accuracy can they be varied. Assuming then that it is simplified to the process of obtaining a definite result by the action of a solvent upon a substance, the conditions of solubility naturally suggest themselves as the solvent and its strength, temperature and time of digestion, degree of agitation and proportion of solvent to substance. In a general sense, to vary any one or more of these conditions is to vary the result. In this study, five hours has been adopted as the time of digestion, it being appropriate to weigh out the samples, digest and filter, in a day's work of seven hours. Two hundred grams of soil per liter are adopted as being comparable with custom and accuracy of solvent effect. The temperature of digestion is fixed at 40°, that being the lowest constant temperature obtainable in summer. The question of agitation is of greatest importance, and constant results could be obtained only in the maximum degree, so continuous shaking is adopted. In comparing the effects of shaking by hand, three or four times per hour, with continuous shaking, in the latter case the results were sometimes more than doubled in the potash, other conditions remaining the same. The method employed in this laboratory is that of the slow upsetting device, usually known as the Wagner machine, and making about 40 revolutions per minute. This has the effect of keeping the soil continuously suspended in the liquid. This machine has been modified by Dr. Wiley so as to permit of digestions being made at definite temperatures. The modification comprises a well-fitted double wall sheet iron chamber, in which the revolving shaft together with the attached flasks, are encased. By use of a thermostat, and owing to the circulation of the air as caused by the revolving of the flasks, such a temperature as 40° may easily be maintained for hours with no more variation than 0.5.°

For a solvent, the simplest mineral acid, hydrochloric, is adopted. The condition admitting of the greatest suscepti-



bility to variation, is the strength of the acid. Hence, with other conditions fixed, a varying strength giving a corresponding varying solvent action, obtains a series of results, from which the one may be selected that is most concordant with the results that the vegetation is known to have obtained.

For an insight into the general composition of the soils, a complete analysis was made of the mineral substance soluble in hydrochloric acid (sp. gr. 1.115), the digestion being made on a steam-bath, using a reflux condenser, with 10 grams to 100 cc. of solvent. The time of digestion being the all-important question, a series of experiments varying as one, five, ten and twenty hours was made on six varieties of soil. Having no knowledge of the previous presentation of a similar piece of work, the results are here given in Table A.

There is noticed a decided increase in the lime, potash, and soda, which is to be expected, as these result from the decomposition of difficultly soluble silicates, which increase would continue until an absolute digestion had been made. Attention is called to the constancy of the phosphorus pentoxide from one to twenty hours.

TABLE A.

Varying time of digestion for complete analysis.
10 grams soil in 100 cc. HCl of 1.115 sp. gr. Digest on steam-bath.

Series No.	Hours digest.	Insol. residue.	Al_2O_3.	Fe_2O_3.	Mn_2O_3.	CaO.	MgO.	SO_3.	P_2O_5.	NaCl KCl.
13767	1	77.23	6.20	4.98	0.08	0.51	1.25	0.06	0.14	0.71
13767	5	72.50	8.45	5.06	0.13	0.83	1.53	0.08	0.14	0.78
13767	10	72.12	9.15	5.50	0.13	0.90	1.61	0.08	0.15	1.06
13767	20	71.33	9.61	5.54	0.13	1.05	1.61	0.08	0.13	1.21
13768	1	85.53	4.46	3.60	0.08	0.52	1.18	0.04	0.06	0.64
13768	5	.....	6.60	3.84	0.08	0.83	1.38	0.04	0.06	0.70
13768	10	81.24	6.50	4.12	0.08	0.97	1.52	0.04	0.06	1.04
13768	20	80.97	6.94	4.14	0.07	1.12	1.53	0.04	0.05	1.12
14094	1	83.43	3.34	3.00	0.08	0.50	0.49	0.07	0.11	0.46
14094	5	80.31	4.37	3.24	0.15	0.62	0.64	0.06	0.11	0.70
14094	10	80.26	5.15	3.32	0.20	0.62	0.68	0.06	0.11	0.97
14094	20	79.55	5.74	3.32	...	0.64	0.67	0.06	0.11	1.13
14095	1	83.72	4.10	3.64	0.08	0.45	0.62	0.04	0.06	0.47
14095	5	80.30	5.84	3.80	0.23	0.55	0.85	0.05	0.07	0.70
14095	10	79.46	6.77	4.16	0.20	0.55	0.85	0.05	0.07	0.92
14095	20	78.13	7.06	4.16	0.20	0.59	0.85	0.04	0.07	1.20
14096	1	77.72	4.14	3.00	0.08	1.30	0.75	0.09	0.18	0.38
14096	5	76.06	5.08	3.08	0.08	1.40	1.03	0.11	0.18	0.70
14096	10	75.14	6.26	3.32	0.10	1.43	1.03	0.11	0.18	0.87
14096	20	74.14	6.52	3.36	0.10	1.46	1.03	0.10	0.18	0.91
14097	1	84.32	4.37	3.44	0.10	0.89	0.90	0.03	0.11	0.47
14097	5	81.65	4.91	3.56	0.21	0.94	1.00	0.04	0.11	0.67
14097	10	81.19	6.36	3.76	0.19	0.98	1.14	0.04	0.11	1.00
14097	20	79.95	6.72	3.80	0.19	1.00	1.13	0.04	0.12	1.21

From a study of this table it was concluded that a digestion of ten hours would give a fairly approximate composition.

In Table B, are given the complete analyses of the soils which are to be considered in this study, together with the average actual yield of each for three successive years, and are graded according to such yield, the conditions of digestion being 10 grams of soil in 100 cc. of hydrochloric acid (sp. gr. 1.115), on a steam-bath, with reflux condenser, for ten hours, shaking every hour.

The determination of total potash and phosphorus pentoxide was also made, the method being to weigh out 2 grams of soil into a 2-inch platinum dish, and ignite over a Bunsen burner to drive off organic matter. Get the soil as much as possible on one side of the dish and put in 1 or 2 cc. of hydrofluoric acid. Allow the soil to come in contact with the acid very slowly to avoid loss by sputtering, using a platinum stirring rod. After the violent action has ceased, place on a steam-bath and evaporate to dryness. Repeat this operation one or two times and then take up with a little hydrochloric acid and water. Filter and wash into a 100 cc. flask, place the filter and contents into the platinum dish and, after drying over the flame, ignite the paper. There will be a small amount of the coarse mineral, which is transferred to an agate mortar to be ground, after which it is again digested in hydrofluoric acid, until there is no insoluble residue left. Take up in hydrochloric acid and water, and add to the original washings.

The method was found to be very easy and rapid of manipulation, and such a method of solution can not be questioned. It is not seen why efforts are made to use methods involving the use of large amounts of sulphuric acid and mercury, or commonly known as a Kjeldahl digestion, when the use of hydrofluoric acid has been made so simple as it is to-day. The results of the total digestion are tabulated in Table B.

It appeared interesting to know how much of the potash and phosphorus went into solution in the successive stages of digestion, and if it was necessary to obtain a complete solution. This was ascertained by keeping the successive digestions separate for analysis. A soil was ignited to drive off organic matter. Two samples of 5 grams each were taken : one was pestled to a rather fine powder, the other remaining in its natural condition. To each was added about 10 cc. of hydrofluoric acid and run down to dryness, taken up with 0.5 cc. of hydrochloric acid and water. Potash and phosphorus were determined in each, the duplicates agreeing. The residues were again digested, and treated as above, no trace of potash or phosphate being found. The second residue was digested as above until a complete solution was effected, in which no phosphate or potash could be found.

Again 5 grams of the same soil were digested with hydrofluoric acid and run down to dryness, and hydrofluoric acid added a second time, again run down to dryness and taken up with hydrochloric acid. The residue weighed 0.70 gram.· This was treated again, the residue weighing 0.25 gram. The next residue weighed 0.15 gram, and the last residue 0.04 gram, or less than 1 per cent. of the original sample. This sample was not ground

TABLE B.

Digestion in HCl of 1.115 specific gravity for 10 hours on steam-bath. Soils arranged in descending magnitude.

Pot.	Insol. Res.	K_2O.	Na_2O.	CaO.	MgO.	Mn_2O_3.	Fe_2O_3.	Al_2O_3.	P_2O_5.	SO_3.	CO_2.	Nitric N.	Total N.	C.	H.	Total K_2O.	Total P_2O_5.	Comparative Grade.
76	80.605	0.766	0.178	0.675	0.615	0.050	2.920	5.527	0.128	0.054	0.048	0.0011	0.173	3.38	0.66	2.491	0.192	100
27	88.252	0.230	0.047	0.405	0.412	0.072	1.756	3.229	0.125	0.050	0.077	0.000	0.090	2.12	0.41	1.970	0.162	98
7	80.553	0.643	0.119	0.575	0.501	0.025	2.880	5.981	0.089	0.042	0.054	0.000	0.174	3.40	0.66	2.418	0.147	93
16	84.692	0.272	0.078	0.405	0.550	0.055	3.136	3.878	0.121	0.068	0.102	0.0046	0.147	2.32	0.61	1.570	0.134	88
90	87.644	0.295	0.060	0.535	0.457	0.085	2.094	3.113	0.163	0.040	0.073	0.0011	0.105	2.06	0.43	1.510	0.262	88
18	80.715	0.731	0.125	0.870	0.907	0.010	3.960	5.455	0.185	0.076	0.052	0.0011	0.146	2.02	0.62	4.356	0.275	80
5	79.809	0.525	0.180	0.610	0.643	0.110	3.440	5.569	0.106	0.081		0.000	0.181	3.27	0.71			80
74	76.480	0.365	0.125	1.185	0.662	0.025	3.040	5.232	0.093	0.081	0.014	0.0049	0.297	5.51	0.85	1.890	0.294	78
65	72.015	0.508	0.115	0.900	1.542	0.050	5.976	9.397	0.117	0.111	0.044	0.0035	0.140	2.72	0.86			75
80	88.666	0.134	0.039	0.405	0.281	0.032	1.746	2.143	0.066	0.038	0.050	0.0029	0.096	5.68	0.40	1.247	0.102	72
14	89.479	0.118	0.043	0.490	0.275	0.037	1.631	1.702	0.064	0.041	0.080	0.0011	0.126	2.96	0.44	1.585	0.096	65
22	84.195	0.390	0.098	0.665	0.628	0.030	2.720	3.817	0.153	0.107	0.070		0.185	2.72	0.66	2.156	0.179	64
9	80.765	0.496	0.116	0.465	0.450	0.045	3.280	5.254	0.166	0.069	0.021	0.0017	0.213	3.42	0.65	1.974	0.192	64
70	74.694	0.479	0.127	1.455	0.989	0.077	3.472	6.348	0.185	0.109	0.068	0.000	0.301	4.95	0.95	1.402	0.275	62
3	88.290	0.161	0.063	0.210	0.247	0.015	1.872	3.913	0.066	0.053	0.037	0.000	0.074	1.85		1.350	0.102	57
25	93.580	0.095	0.051	0.175	0.162	0.050	0.800	1.788	0.032	0.034	0.054	0.000	0.077	1.15	0.27	1.062	0.083	57
19	85.525	0.321	0.047	0.250	0.518	0.070	3.000	3.536	0.189	0.045	0.067	0.0017	0.122	2.81	0.51	1.751	0.281	51
12	83.555	0.153	0.122	0.525	0.558	0.015	3.880	4.476	0.144	0.063	0.053	0.0023	0.114	2.76	0.52	1.527	0.409	51
51	88.620	0.351	0.122	0.140	0.585	0.040	3.320	4.057	0.156	0.046	0.059	0.0011	0.037	0.86	0.37	1.867	0.243	51
87	86.305	0.365	0.071	0.710	0.585	0.040	2.360	2.923	0.147	0.085		0.0022	0.073			2.190	0.166	51
39	81.920	0.337	0.116	0.790	0.585	0.040	3.120	4.618	0.137	0.044	0.068	0.0024	0.168	3.18	0.62	1.829	0.160	48
63	74.357	0.594	0.286	1.535	1.726	0.050	5.640	7.697	0.163	0.068	0.024	0.0017	0.045	0.82		1.815	0.339	48
69	90.629	0.156	0.053	0.230	0.218	0.020	1.476	2.945	0.070	0.043	0.048	0.0011	0.095	1.58	0.28	1.494	0.070	48
73	81.970	0.384	0.114	0.370	0.450	0.040	3.400	5.370	0.105	0.047	0.010	0.0024	0.158	2.59	0.60	1.856	0.160	48
84	80.570	0.747	0.132	0.970	1.105	0.040	4.280	6.119	0.176	0.073		0.0073	0.129					48
29	85.198	0.204	0.077	0.102	0.299	0.088	2.727	5.323	0.168	0.044	0.071	0.0024	0.080	1.69	0.54	1.278	0.172	48
31	77.680	0.480	0.283	1.415	1.661	0.085	5.280	7.108	0.147	0.098			0.096	1.20	0.69	1.905	0.281	45
89	94.330	0.053	0.008	0.150	0.104	0.005	0.800	1.820	0.035	0.022	0.016	0.0046	0.068	1.01	0.25	1.095	0.089	45
1	77.500	0.554	0.127	0.955	1.052	0.055	4.640	6.920	0.230	0.100	0.031		0.169	2.48	0.69	1.768	0.384	38
85	86.750	0.246	0.111	0.125	0.549	0.040	3.040	3.635	0.202	0.066	0.061	0.0028	0.105	2.08	0.44	1.805	0.313	33
104	79.813	0.733	0.127	0.525	0.687	0.040	3.640	7.160	0.090	0.068	0.030	0.0024	0.111	2.05	0.61	2.592	0.147	33
93	77.783	0.509	0.132	1.005	1.085	0.130	4.840	6.372	0.233	0.083			0.106			1.907	0.300	27
101	91.221	0.193	0.061	0.157	0.248	0.040	1.623	3.412	0.051	0.018	0.024	0.0017	0.046	0.82	0.31	1.565	0.083	19
35	79.604	0.580	0.167	0.520	0.886	0.065	4.200	6.935	0.085	0.053	0.051	0.000	0.093	1.84	0.67			19

previous to digestion, and the residue was probably some coarse matter that was decomposing slowly.

Then a series of samples were digested as above, hydrofluoric acid being added the second time before taking up in hydrochloric acid. All the residues were put together and brought into complete solution. No phosphate or potash was found, which is good evidence that not even a complete digestion is essential.

The mechanical composition of the soils also, is illustrated in Table C.

TABLE C.

Arranged in descending magnitude. Mechanical composition of the soils.

	Per cent.								
Pot.	mm. >0.25.	mm. >0.10.	mm. >0.05.	mm. >0.025.	mm. >0.012.	mm. >0.006.	Will not float 18 hrs.	Will float 18 hrs.	Loss on ignition.
76	1	4	28	32	7	3	8	8	8
27	4	10	12	25	16	9	10	7	5
7	2	4	26	35	7	3	7	9	9
16	2	4	16	37	9	5	11	9	7
90	2	4	12	27	20	9	11	7	5
18	2	5	31	20	15	4	6	9	7
5	..	..	..	..	..	..	..	..	..
74	13	23	11	14	12	3	4	7	12
65	1	13	8	15	8	4	18	13	9
80	12	36	21	7	8	4	2	2	5
14	20	37	15	7	7	3	2	1	6
22	14	30	16	14	9	3	2	5	7
9	3	4	9	26	11	9	18	9	9
70	2	6	7	25	10	6	15	15	2
3	2	14	17	34	11	6	12	8	2
25	1	32	33	11	10	3	2	5	3
19	21	20	15	15	9	3	8	1	7
12	3	9	52	20	3	2	2	2	6
51	21	24	15	13	6	3	10	5	2
87	14	21	22	11	8	2	1	4	6
39	14	20	16	16	6	4	8	7	8
63	6	14	20	11	15	5	8	14	7
69	2	5	12	34	19	9	8	7	4
73	6	5	9	22	27	6	8	7	7
84	1	2	30	20	16	4	8	12	6
29	11	15	11	19	8	7	15	9	6
31	7	20	24	11	10	5	7	11	5
89	1	27	42	8	7	5	3	5	2
1	10	17	18	12	12	5	8	11	8
85	18	23	16	13	6	3	9	5	5
104	1	2	19	32	7	4	12	16	7
93	10	17	19	11	12	5	8	10	8
101	2	5	12	33	20	8	7	9	3

In this, a method was to some extent improvised, it being in the main the beaker decantation, or what is more generally known as the Osborne method. The radical change was a method devised for the disintegration of the sample. Instead of pestling with a rubber-tipped pestle, the sample was agitated in water by means of a shaking machine. Twenty grams of soil were put into a cylindrical bottle, the ordinary 8 oz. sterilizing bottle being used, with about 150 cc. of water, and the bottle shaken about one hour at the rate of 150 strokes per minute. A frame was constructed to hold ten or more such bottles. The method proved admirable in every respect. Samples shaken one hour and one week gave constant results, disproving any grinding of particles. The siftings were made through sieves and bolting-cloth, the decantations controlled by the microscope. Below 0.006 mm., the decantation could be made with no accuracy, and resort was had to an arbitrary floating method. The period of eighteen hours was selected, as it was convenient to arrange for the settling at the close of a day's work, and to decant the next morning. This decantation or what is specified as "does float eighteen hours," was determined by difference.

While this separation of particles below 0.006 mm. is altogether arbitrary, it is no more so than the practice of endeavoring to measure with the microscope, and decant particles below that size, the inaccuracy of measurement being so great. In this work, the writer found it very convenient to make the coarser separations in the working hours, and at the close of each day, to stir the sediment and allow to stand until it could be decanted next morning, the time being about eighteen hours. It took five or six days to complete the separations, and that many decantations of eighteen hours' standing gave a clear decantation at the last, after which the residue was weighed to represent that portion that was below 0.006 but would not remain in suspension eighteen hours.

As this paper will relate to the oat plant, only data for such pots will be presented. In most instances the subsoils failed to make what could be called crops, so these and the muck soils, being abnormal conditions, were not considered, except in a few instances, while again, some of the so-called subsoils were practically soils, the subsoil being the second six inches. In some other cases there was insufficient sample to admit of the work, so the data given is not a selection, but comprises all soils which produced crops, and of which there was sufficient sample for study.

The crop data for the five years since the first planting, is illustrated in Table D.

The weight of soil in the pots varies from 23 to 30 kilos. The crop weights are expressed in parts per 100,000 of the soil, while the ash, nitrogen, potash and phosphorus pentoxide are expressed in parts per 1,000,000 of the soil. This method of expression makes the results comparable. It is observed there are two columns under each of the headings. In all cases, the left column refers to the first crop, oats, and the right column, to the second crop of that season, buckwheat. For illustration, pot 1 contains 31.1 kilos of soil. It was not planted until 1896, when the weight of the oats in parts per 100,000 is expressed as 159, and the following buckwheat crop as 105. The crude ash of the oats is expressed in parts per 1,000,000 of the weight of the soil as 197, and of the following crop of buckwheat as 124. The nitrogen is: oats 18 parts per 1,000,000, and buckwheat 13; potash in oats as 60, in buckwheat as 36, and phosphorus pentoxide in oats as 16, and buckwheat 12. Continuing horizontally, the crops and their respective analyses are expressed for each subsequent year in a similar manner.

In pot 3, it is seen that there was a crop of oats raised in 1895, but no second crop of buckwheat, while thereafter the two crops were raised annually.

In an average crop of oats of 45 bushels per acre, if the weight of total crop be computed on the area of a circle 12 inches in diameter, which is the area of the pot, and that weight compared with the average weight of soil in the pots, and expressed in parts per 100,000, the ratio will be 100; that is to say, under the column headed "crops," the normal crop will be expressed by 100.

It is noticed that many of these crops are very much above the normal. But when it is considered that the moisture and temperature, have been ideal, and that some of the soils are of our richest virgin types, it is anticipated that the crop will utilize all assimilable food, provided there is an approximate balance of the essential elements; that is to say, a soil with a superabundance of potash, and a decided deficiency of phosphate, is not ex-

TABLE D.—Annual yields expressed in parts per hundred thousand of the soil. Crop composition expressed in parts per million of the soil. First column under each head is oats. Second column is buckwheat.

Pot.	Kilos of soil.	*Year 1895.*										*Year 1896.*										*Year 1897.*										*Year 1898*										*Year 1899.*									
		Crops.		Ash.		N.		K_2O.		P_2O_5.		Crops.		Ash.		N.		K_2O.		P_2O_5.		Crops.		Ash.		N.		K_2O.		P_2O_5.		Crops.		Ash.		N.		K_2O.		P_2O_5.		Crops.		Ash.		N.		K_2O.		P_2O_5.	
1	31.1											159	105	197	124	18	13	60	36	16	12	99	62	122	88	14	10	36	25	10	10	84	52	105	62	11	13	31	19	10	6	95	31	112	30	14	7	43	8	10	3
3	23.9	130		170		10		42		4		146	34	156	45	18	9	43	11	5	1	86	26	112	37	10	7	30	8	3	1	84	14	116	12	11	3	30	3	3		68	61	93	82	12		23	21	2	3
5	24.5	253		388		36		79		8		122	102	150	104	18	18	41	30	3	4	122	60	149	94	18	14	35	19	5	2	68	18	100	86	27	16	25	27	5	3	70	65	99	77	12		26	19	2	1
7	23.1	252		340		48		98		8		173	107	221	139	22	23	55	36	7	3	162	103	206	113	23	20	61	32	5	2	101	33	136	41	22	8	41	10	5	2	80	56	129	85	17		30	19	2	3
9	15.6											153	192	141	177	23	26	42	63	5	7	117	172	64	168	15	31	19	48	4	20	134	75	152	87	24	19	27	24	5	6	134	24	110	51	22	11	26	12	4	3
12	22.6											136	78	117	80	17	12	26	17	7	3	86	30	93	40	11	5	13	4	6	1	97	9	85	13	17	2	13	2	4		61	66	61	84	10		10	9	2	2
14	28.0	156		170		18		40		7		169	133		117		19				7	84	75	96	94	9	17	20	16	4	4	100	19	114	26	14	6	17	5	4	1	102	15	106	16	20	3	17	5	2	1
16	24.0	238		270		36		55		8		199	160	209	221	20	25	44	42	4	7	110	117	123	128	11	26	37	30	4	5	81	30	104	36	15	8	12	8	4	2	143	8	167	13	25	3	23	3	6	0
18	22.8											224	161	295	166	26	22	82	60	15	12	136	120	210	132	16	25	55	46	12	12	140	58	213	72	15	15	59	26	11	4	153	65	249	57	24	16	55	10	10	2
19	28.7											181	155	216	163	25	26	76	60	17	20	102	135	126	135	16	25	36	44	12	13	43	60	72	68	9	14	14	22	2	5	60	40	86	39	16	8	23	10	4	3
20	25.7											75	100	131	99	11	14	24	32	12	12	90	70	121	74	9	15	14	21	9	8	78	56	105	63	10	14	19	13	10	4	73	12	114	12	9	2	15	4	8	1
22	26.1											172	121	211	124	20	19	58	31	5	4	141	114	170	111	16	23	44	34	3	4	95	46	135	52	10	12	31	18	3	2	98	20	140	22	14	5	26	8	4	1
25	28.1	170		240		20		41		5		101	74	129	67	12	11	29	20	4	2	87	48	116	56	9	10	20	13	3	2	67	14	86	15	8	2	15	3	3	0	45	8	60	13	5		8	2	2	
27	26.1	319		400		48		77		21		187	146	217	168	23	21	39	36	19	17	110	138	132	139	16	23	21	22	13	13	122	50	126	57	18	12	18	8	13	4	139	47	174	55	21	12	52	7	14	4
29	26.2	120		110		13		35		6		110	51	101	54	13	10	15	15	6	2	73	15	76	32	10	4	17	5	5	1	86	3	86		12		19		5		75	2	11		11		14		4	
31	26.6											130	73	178	72	11	10	41	22	16	9	70	76	44	89	7	13	24	23	14	15	80	36	106	57	12	10	30	17	12	6	78	32	100	32	13	6	23	8	9	3
35	24.3	63		70		9		18		1		33	24	39	26	5	4	8	5	1	1	26	24	39	20	5	4	9	5	1	1	24	6	25	14	4	2	8	2			28	3	43		5		10		1	
39	23.8											133	75	165	53	12	12	33	18	6	4	79	117	101	108	10	19	16	30	1	7	94	62	119	69	10	12	15	16	6	3	113	24	143	20	13	4	16	4	6	2
51	29.1	214		210		19		65		10			114		46		8		14		6	29	42	36	55	4	6	3	8	2	2	21	21	25	21	4	4	4	6	1	2	30	10	43	11	6	2	5	3	1	1
63	27.0											176	76	236	76	17	12	62	25	14	9	71	73	98	134	10	10	21	21	15	7	58	42	83	49	9	9	21	12	8	4	73	25	89	32	10	6	21	8	8	3
65	20.5	278		400		53		66		5		71	71	53	66	8	15	13	22	5	3	123	70	136	76	16	16	31	23	6	3	117	3	154		16		37		9		143	1	176		23		30		5	
69	26.1	105		130		13		33		4		115	58	136	56	15	12	37	6	4	2	80	50	99	53	10	11	22	13	4	1	73	5	106	24	13	5	26	5	3	1	73	5	84		11		19		3	
70	22.6	200		238		28		46		12			106		122		15		21		6	102	100	11	11	14	2	28	2	7	1	71	65	99	80	13	14	22	17	5	3	4	3	62	42	11	9	11	8	2	1
73	24.2											112	141	118	116	13	21	18	31	5	5	96	87	111	92	14	17	17	22	6	3	93	22	93	22	13	5	14	5	4	1	68	7	84	26	13		13	2	3	0
74	21.8											188	188	255	155	25	33	49	42	11	13	160	150	214	174	23	34	28	32	8	9	141	54	160	76	22	14	30	12	1	4	84	24	148	25	17	5	19	5	5	1
76	24.5											250	223	488	98	26	24	98	76	29	15	200	150	319	159	25	29	92	53	16	11	178	53	288	84	29	13	89	23	11	5	198	27	295	39	34	7	83	10	11	2
80	26.8	144		198		16		41		6		182	151	177	118	24	22	53	46	10	8	128	99	133	100	20	20	34	32	8	0	124	19	117	24	18	5	23	5	6	1	104	5	98	14	17		19		5	1
84	27.0											137	100	186	89	15	15	46	30	12	9	82	89	113	112	12	14	28	9	8	4	82	47	109	57	9	9	18	16	8	4	52	21	82	20	6	4	16	5	7	1
85	27.7											76	142	138	150	13	21	34	46	11	13	73	137	100	146	13	41	22	41	4	11	61	37	84	56	13	10	15	13	4	3	69	11	102	13	14	2	21	3	4	1
86	25.6											255	157	343	160	36	22	99	58	27	17	128	119	182	187	16	19	40	55	24	17	127	68	181	86	19	18	49	23	26	7	157	15	230	25	24	5	49	5	27	1
87	28.1											156	127	176	114	24	21	46	32	5	6	88	87	113	96	11	18	24	22	5	4	79	50	98	56	9	12	20	13	3	2	75	36	98	37	12	9	19	9	3	2
89	25.5											116	79	180	170	16	12	31	25	4	2	103	83	129	82	12	15	30	25	3	3	64	8	60	31	9	2	12	2	3	0	50	7	74		7		10		2	
90	24.5	250		330		28		71		25		143	158	182	149	16	20	39	44	20	15	118	143	185	80	12	24	38	36	19	16	145	66	182	83	17	7	41	17	23	7	102	57	146	58	16	14	27	12	2	6
93	26.7											106	38	150	33	8	5	37	9	6	3	30	54	52	49	3	6	7	13	5	6	33	31	40	36	3	5	9	10	4	2	30	15	41	10	4	2	9	2	3	1
101	25.5	110		120		11		31		4		36	9	68	13	4	2	10	3	2	0	32	13	48	13	4	2	7	4	1		51		53		6		16		2		36		49		3		11		1	
104	24.5											132	56	146	54	15	8	45	15	5	2	62	56	77	67	7	11	19	14	3	2	22	19	28	37	4	5	7	5		1	37		58		7		14		1	
115	26.9											43	5	50	11	4	2	11	3	1		9	4	15	12	1		3	3	1	1	10	7	15	23	1	2	4	3	1		21	7	24	12	3	2	5	3	1	
117	26.5											45	10	75	10	12	2	10	2	2	1	55	24	83	18	14	3	16	6	3	2	51	17	67	22	14	4	15	6	4	2	36		64	14			11		3	
156	34.5																					51	74	65	83	11	15	21	16	3	3	71	10	104	12	12	3	21	3	4	1	87		94		17		21		3	
158	31.8																					107	88	120	106	19	17	30	19	10	11	88	18	109	29	13	6	18	4	8	3	152	15	159	28	27	6	26	4	8	2
160	32.7																					64	56	76	75	9	13	24	16	4	3	75	34	100	13	10	3	24	3	4		101		98		16		18		3	
162	32.7																					119	120	172	144	19	20	76	47	15	14	112	32	154	43	13	10	50	15	12	3	173	29	240	37	21	7	71	9	11	2
164	32.7																					90	87	102	104	12	18	29	21	13	13	87	21	113	27	11	7		4	10	2	116	15	146	17	14	3	16	2	6	0
166	32.7																					68	82	99	103	11	16	34	26	6	4	109	22	162	26	22	5	49	7	6	1	101		126	1	14		35		4	
168	32.7																					119	104	173		17	16	64		16		100	50	154	63	12	12	38	21	12	5	140	23	172	29	15		57	6	10	2
170	32.7																					71	75	90	72	10	11	30	18	4	4	81	28	88	33	10	7	21	7	5	1	97	13	124	12	14	2	22	3	4	

pected to furnish to the crop all of its available potash, or as much as it would were the deficiency in phosphate made up. Further, it is rational to expect that, with a soil abounding in one element, as potash for example, and deficient in another, as phosphate, the crop would feed more greedily on the deficient element, in its effort to make a balance in its composition. In other words, a crop feeding on a soil highly supplied with one element, and deficient in another, would take from the soil more of the deficient element than would be considered available under normal conditions.

In a study of Table D, it is seen that the columns headed K_2O, and P_2O_5, are very indicative. There is shown here the actual amounts that the crop obtained under ideal conditions of climate. Can not the ratios 60 and 16, as shown in pot 1, be interpreted as representing the available amounts of potash and phosphate, which the soil held ready for that crop at the time of planting, assuming of course the possibility that one of these elements may be largely in excess of that required for a balanced composition? There is no other standard for what a soil should do, than what it actually does under ideal climatic conditions.

It is readily conceived that while the mineral matter in a soil is not soluble in water, still some of it may exist in such a degree as to become soluble in the acids in the sap of roots. If we know how much the root acid was able to dissolve, can not any simple acid be diluted until it will accomplish the same result? Accordingly, the results sought are those under the headings K_2O, and P_2O_5 in the left column as representing the available potash and phosphate respectively.

The simplest acid, hydrochloric, and the solvent conditions as previously referred to, are taken with the purpose of diluting the acid, until its solvent effect reaches a point where it is comparable with the actual conditions.

A preliminary digestion is made to determine the basicity of the soil, and a correction made in the strength of the acid so as to reduce the solvent action to a uniform basis. It is understood that where a digestion is spoken of as being made in N/50, for illustration, that the solvent was stronger than N/50, but after digestion, the filtrate was N/50. For example, 20 grams of soil were digested in 100 cc. of N/10 hydrochloric acid for five hours at 40°, constant shaking, and 10 cc. of filtrate titrated with N/10 alkali, using methyl orange as an indicator to avoid carbon dioxide. Suppose 9 cc. of alkali are required to neutralize. Then 1 cc. of acid was neutralized by the basic matter, and consequently 1 cc. additional of the N/10 acid must be allowed for, or 10 cc. of an unknown strength must be the equivalent of 11 cc. of N/10. Therefore, 10 cc. N/*X* must equal 11 cc. N/10, or *X* equals 9; that is, the solvent should be N/9 in order to have a filtrate N/10.

While it is not exactly theory, it is within the limit of error that a solvent of strength of N/90 on such a soil gives a filtrate of N/100. In like manner, N/180 gives a filtrate of N/200.

A series of results were obtained in N/10 hydrochloric acid. They ranged from two to seven times the results as shown in the crops. A second series in N/25 acid, other conditions remaining the same, gave in some soils about half that obtained in the N/10, while in others nearly the same. In the same manner, the strength of the acid was successively divided until the dilution corresponded to N/200. The results are tabulated in Table E.

In Table F, a comparison is made between the results obtained by the crop, and those obtained by a digestion in N/200 hydrochloric acid, the soil sample being taken before planting.

The two columns on the left are expressed in parts per 1,000,000 of the soil, soluble in N/200 hydrochloric acid, and the two columns on the right are parts per 1,000,000 of the soil taken up by the crop, these results being taken from Table D. The results are most striking. In pot 1, the ratios of 16 and 65 against 16 and 60 are singularly coincident, and represent a soil well balanced in plant food. In the following year, there was but half the amount of phosphate available, and apparently more potash. Pot 3 shows a soil most deficient in phosphate and abundant in potash. It is reasonable to suppose that on such soils, a crop would be ravenous for phosphate and so feed on phosphate that would not be considered available under normal conditions, while at the same time it would not utilize all of its available potash. This is the best illustration of a soil unbalanced in plant food. By reference to Table D, it will be seen that the soil shows its poverty throughout. Pots 5, 7, and 9 are also poorly balanced. Pot 12 is decidedly an inferior soil in mineral food. While the acid-soluble potash is coincident with the crop result, it would not be expected that the crop would obtain comparatively so much phosphate. However, it is ex-

TABLE E.

Successive Digestions in Acids of Different Strengths.

	P_2O_5.							K_2O.						
	Per cent.		Parts per million.					Per cent.		Parts per million.				
Pot.	Total.	strong HCl.	$\frac{N}{10}$	$\frac{N}{25}$	$\frac{N}{50}$	$\frac{N}{100}$	$\frac{N}{200}$	Total.	strong HCl.	$\frac{N}{10}$	$\frac{N}{25}$	$\frac{N}{50}$	$\frac{N}{100}$	$\frac{N}{200}$
1	0.384	0.230		105	63	35	16	1.768	0.554					65
1*							8							84
3	0.102	0.066			2	2	2	1.350	0.161			144	129	102
3*						4	2						116	92
5		0.106		6	6	5	5		0.525			191	153	105
7	0.147	0.089			15	10	7	2.418	0.643			223	166	144
7*						9	7						133	101
9	0.192	0.166					5	1.974	0.496					77
12	0.409	0.144			6	2	1	1.527	0.153				104	
12*							1							27
14	0.096	0.062	41	24	13	13	9	1.585	0.118	184	182			45
14†					8	7	4					57	55	31
16*	0.134	0.121					2	1.570	0.272					40
16†					70		1					131		41
18	0.275	0.185		280	114	24	10	4.356	0.731		425	310	235	175
19	0.281	0.189		48	27	20	18	1.751	0.321			405	317	235
19†					21	13	12					230	173	134
20					5	5	5					44	30	28
22	0.179	0.153		50	20	5	4	2.156	0.390				147	66
25	0.083	0.032		16	15	15	11	1.062	0.093		76	74	58	47
25*					8	8	8					61	44	37
25†					6	4	3					56	48	38
27	0.162	0.125	128	60			18	1.970	0.230	127	107	80	64	60
27†							16							54
29	0.172	0.168	37	13	4	1	1	1.278	0.204	135	98	94	86	80
29*						1	1						70	58
29†					3	1	1					82	66	63
31	0.281	0.147				34	16	1.905	0.480				24	20
31†							18							69
35		0.083	2	2	1	1	1		0.580	168	168	115	69	69
39*	0.160	0.137				5	4	1.829	0.337				28	20
51	0.243	0.153			30	13	3	1.867	0.351			99	90	76
63	0.339	0.163		122	112	57	25	1.815	0.594		225	159	110	84
63*					91	33	21					160	105	71
65		0.117					2		0.508					50
69*	0.070	0.070					1	1.494	0.156					47
70	0.275	0.185					14	1.402	0.479					24
73	0.160	0.105		2	2	2	1	1.856	0.384				67	27
74*	0.294	0.093					20	1.890	0.365					30
76	0.192	0.128		57	42	42	33	2.491	0.766		920	705	560	525
76*							31							402
76†					25	23	13					626	452	366
80	0.102	0.066			10	6	5	1.247	0.134			171	171	170
80*							4							67
84		0.176					9		0.747					88
85	0.313	0.205		44	44	17	10	1.805	0.246			283	238	171
86				74	40	26	25				377	191	148	118

* Second year. † Third year.

TABLE E.—*Continued.*

	P_2O_5.							K_2O.						
	Per cent.		Parts per million.					Per cent.		Parts per million.				
Pot.	Total.	Strong HCl.	N/10	N/25	N/50	N/100	N/200	Total.	Strong HCl.	N/10	N/25	N/50	N/100	N/20
87	0.166	0.147		44	25	5	2	2.190	0.365			72	50	45
89	0.089	0.035		22	19	13	13	1.095	0.053			103	88	74
89*			28				11							61
90	0.262	0.163		104	68	68	68	1.510	0.295			103	74	58
90*					62	55	42					95	74	46
90†					44	44	27					88	72	58
93	0.300	0.233		101	64	57	25	1.907	0.509			93	88	46
93*					60	16	5					178	78	66
101	0.083	0.051					1	1.565	0.193					31
104	0.147	0.090		15	10	2	1	2.592	0.733		361	280	159	166
104†					2	1	1					233	171	147
115							1							16
117							3							12
156							1							27
158							5							27
160					1	1	1					28	28	22
162							4							147
164					4	2	2					27	25	17
166					1	1	1					199	180	160
168					15	10	6					209	156	127
170							1							35

* Second year. † Third year.

pected that the crop would feed ravenously for phosphate, and so take up more than is apparently available. Pot 18 is another illustration of superabundant potash. By referring to Table E, it will be seen that in N/100 acid there is two and a half times as much phosphate soluble as in N/200; that is to say, there is much phosphate just beyond the line of that interpreted as being available, so it could be foretold that with so much available potash, more phosphate would be assimilated. Pot 19 is in striking contrast. Here is a great excess of potash shown to be available, but, as seen in Table E, there is but one-ninth more soluble in double the strength acid. Consequently, this soil would not be expected to supply much more phosphate than that interpreted as available, even though the potash is most abundant. In pots 20 and 22, the interpreted plant food is nearly coincident with the actual conditions. In pot 25, the food elements are poorly balanced, the potash figures agreeing very well and showing a deficiency in potash. Pot 29 seems totally lacking in available phosphate, and well supplied in potash. Pots 31 to 51 are virgin subsoils. It is interesting to note the change in the

TABLE F.

Comparison of mineral matter soluble in $^N/_{200}$ HCl, with that taken off by crop.
[Parts per million.]

	Proposed available.		Taken off by crop.		
Pot.	P_2O_5.	K_2O.	P_2O_5.	K_2O.	Type.
1	16	65	16	60	Vir. sur.
1[1]	8	84	10	36	"
3	2	102	4	42	"
3[1]	2	92	5	43	"
5	5	87	8	79	"
7	7	144	8	98	"
7[1]	7	101	7	55	"
9	5	77	5	42	"
12	1	27	7	26	"
14	9	45	7	40	"
14[1]	4	31	4	20	"
16	2	40	4	44	"
16[1]	1	41	4	37	"
18	10	175	15	82	"
19	18	235	17	76	"
19[1]	12	134	12	..	"
20	5	28	..	24	"
22	4	66	5	58	"
25	11	47	5	41	"
25[1]	8	37	4	29	"
25[2]	3	38	3	20	"
27	18	60	21	77	"
27[1]	16	54	13	..	"
29	1	80	6	35	"
29[1]	1	58	6	15	"
29[2]	1	63	5	17	"
31	16	20	16	41	Vir. sub.
31[1]	18	69	14	(24)	"
35	1	69	1	18	"
39	4	20	6	33	"
51	3	76	10	65	"
63	25	84	14	62	Cul. sur.
63[1]	21	71	15	21	"
65	2	50	5	66	Cul. sur.
69	1	47	4	37	"
70	14	24	12	46	"
73	1	15	5	18	"
74	20	30	11	49	"
76	31	402	29	98	"
76[1]	13	366	16	92	"
80	5	170	6	41	"
80[1]	4	67	10	53	"
84	9	88	12	46	"
85	10	171	11	34	"
86	25	116	27	99	"
87	2	45	5	46	"
89	11	61	4	31	"
90	68	58	25	71	"
90[1]	42	46	20	39	"
90[2]	27	58	25	31	"
93	25	46	6	37	"
93[1]	5	34	5	7	"
101	1	31	4	31	Cul. sub.
104	1	166	5	45	"
104[1]	1	147	3	19	"
115	1	16	1	11	"
117	3	12	2	10	"
156	1	27	3	21	W10*a*
158	5	27	10	30	W11
160	1	22	4	24	B1A
162	4	147	15	76	W13
164	2	17	13	29	B2A
166	1	160	6	34	B3A
168	6	127	16	64	B4A
170	1	35	4	30	W3

[1] Second year.
[2] Third year.

soil in 31 after one year, the potash increasing from 20 to 69. This is the subsoil of pot 1, and it will be noticed that the phosphate is the same, while in the second year the potash is the same. The soil and subsoil are practically the same, as will be seen in the mechanical analyses. In pot 51 it will be noticed that the crop fed more on phosphates than shown in the analysis. By Table E, it will be seen that the phosphate went from 3 to 13 in the next strength acid, showing that more phosphate was very nearly available, and which became so after the subsoil had been exposed to the air.

This concludes the virgin soils that were studied. Pots 63 to 90 inclusive, are cultivated soils. Pot 63 is overbalanced in phosphate. It would be expected that more than 84 parts of potash would be utilized, rather than only 62. This crop as seen in Table D, is impoverished in nitrogen. It is more probably suffering for want of a better crop rotation system. It will be noticed that the crop is two and a half times greater the first year than in the second. Pots 65 to 74 are similar to soils, to which reference has been made. Pot 76 is extraordinarily fertile, so far as the immediately available phosphate is concerned. But in Table E, it is noticed that in N/100 acid, about one-fourth more is soluble than in N/200, while N/50 gives no increase over N/100. In this soil, the first crops would be expected to abound in phosphate, followed by a rapid deterioration in that element. This is noticeable in the following year, where the phosphate falls to 13, and throughout the crop records of that soil. Pot 85 is fairly well supplied in phosphate and potash, but the crop is only 76, or about three-fourths a normal crop, so the soil is suffering for some other essential element, or more probably from improper crop rotation. Pot 86 is the best type of a soil balanced in these plant foods, its crop being about two and a half times the normal.

The ratio of 25 parts of phosphate to 100 parts of potash, seems to be the ideal condition. This ratio of 1 to 4 seems to exist in most of the soils.

In pot 89 there is a discrepancy not understood when the phosphate and potash only are considered. Pot 90 contains more than double the amount of available phosphate that is found in any other soil, but its deficiency in potash is foreseen. The waver in the potash as seen in the three years in which this soil was studied, is proportional to the waver shown in the cropping, the first and third years being constant, with the drop in the middle.

Pots 93 to 117 are subsoils upon which the same diagnosis seems to hold. Subsoils are an abnormal condition, and so few of them produced a crop that not much can be seen from the small data here presented.

Pots 156 to 170 are soils taken from the famous wheat and barley fields of Rothamsted, England. As is well-known, these fields have been under continuous study for more than half a century. The plot references as given in the Rothamsted memoranda, are shown in the column headed W10*a*. Some of these plots have been treated with excessive quantities of artificial plant food, as ammonia salts, sulphates of potash, soda, and magnesia, and superphosphate of lime, so that the condition is most abnormal in cases where all of these compounds have been applied to a single plot. In pots 156, 160, and 170, only nitrogen has been applied. In these pots the interpreted potash is nearly coincident with the crop record, and the phosphate is shown to be as deficient in the crops as would have been anticipated from the soil analysis. Pot 158 has had continuous application of superphosphate. This is shown in the analysis but not to the extent taken up in the crop. It is well-known that the available phosphate in a superphosphate is constantly reverting to an insoluble form, and it is rational to suppose that, as this sample of soil was on hand for over three years before the analysis was made, in that time some would have reverted that would have been soluble, had the analysis been made at the time the crop was planted. However, the potash is seen to be practically coincident. In pot 162, superphosphate and potash had been added. The increase of available potash is shown in the analysis and in the crop, it not being expected that the total available would be utilized, as has been pointed out in previous cases of a superabundance of one element. The increase in the phosphate is shown, but not to the extent indicated by the crop for the reasons as cited in reference to pot 158. All of the soils have been studied nearly four years after the sample was taken. In pot 164, only superphosphate has been added. As this soil is similar to pot 158 in the matter of potash, it is more than probable that the result 17 is low, due to an analytical error. By a reference to Table E, it is seen that these soils are nearly identical in potash in the N/100 and N/50 digestions. Pot 166 has been treated with potash as is shown in the analysis, but deficient in phosphate, while pot 168 has received both potash and phosphate, as is shown in the analysis. The same condition in the matter of phosphate exists, as was referred to in pot 158.

Now to look at this Table F, as a whole, there are about 65 pots studied, covering a range of soil types from Massachusetts to California. The soils have been taken with the one purpose of having as much variation as possible. It is not a selection of evidence that is comparable, but is all the material that was available for study. With the exception of about two instances, the analyses indicate, to a remarkable degree of accuracy, the conditions as brought out in the crops. Just how much circumstantial evidence is necessary to establish a fact, is always questionable, and whether the data here given is sufficient proof, is not the province of any one man to decide, as to its being a means for forecasting the mineral plant food available for an oat crop.

The simplicity and rapidity of the method will undoubtedly appeal to any one. All chemists have noticed the degree to which analytical methods may be simplified by actual experience. In this method the ratio of substance to solvent was 200 grams per liter. However, a liter flask was used in which 186 grams of soil were placed, and the solvent added up to the mark. This varied only 1 or 2 cc. from 930, which was the ratio desired. After the digestion the whole was shaken and emptied on to a fluted filter sufficiently large. After draining, the volume of the filtrate did not vary 10 cc. from 800. This was shown in so many cases, that the filtrate was no longer measured, but taken as 800 cc., corresponding to 160 grams of the soil. This expedited the work greatly, and avoided the recording of figures, and the chance for mistake. To this filtrate was always added 1 or 2 cc. of nitric acid for the double purpose, of decomposing any ammonium chloride which may have been formed in the digestion of organic matter, and also to oxidize any organic matter in solution. After evaporating to dryness, hydrochloric acid was added repeatedly and evaporated until there was no further evidence of the presence of nitrates. The residue was now transferred to a smaller porcelain dish, and diluted to about 50 cc. with water. To this was added 2 cc. of platinum chloride, according to the method of direct estimation of potash as found in this Journal, **20**, 340 (1898). The solution was slowly concentrated until the potassium platinichloride could be crystallized on the sides of the dish, after which it was set off to cool and solidify. It was then treated with acidified alcohol as described in the method referred to, washed onto a paper filter, and washed with plain alcohol and then with the half-saturated solution of ammonium chloride, according to the usual method. After drying the salt, it was dissolved and washed through with hot water into small platinum dishes, evaporated to dryness, dried at 100°, and weighed. The filtrates were set aside after the washing with ammonium chloride, stirred up and the ammonium platinum chloride allowed to settle over night. Most of the liquid can then be decanted into porcelain evaporators. The residue is washed onto a filter with alcohol three or four times, the washings being added to the original solution for evaporation. A rather large dish should be used and the evaporation carried on slowly, until the alcohol is completely volatilized. There is left a large residue of ammonium chloride, which should be well diluted with water. and 2 or 3 cc. of nitric acid are added. The dish should be covered at first and warmed very gently to avoid loss by spirting. After the salt has been decomposed, the evaporation may be completed. The residue is taken up with water and a few drops of nitric acid, and the determination of phosphorus pentoxide made according to the usual molybdate method, titrating the yellow precipitate. It is seen that the results in potash and phosphorus pentoxide are to be calculated on the original 160 grams of soil, which is a great advantage in accuracy over dividing the original solution.

As to the accuracy with which these results can be obtained, the writer has found no more variations in duplicates, where the results are expressed in parts per million than in analytical determinations where the results are expressed in parts per hundred. Several sets of samples were repeated through mistake, the results being practically the same in all cases, and in some, identical.

By following such a procedure, the writer has found it very easy to make such analyses, averaging ten samples per day of seven hours' work, where the evaporations could continue through the night. Samples could be completed within four days. The daily expenditure, including salary of the analyst, chemicals, portion of house rent and the help of porter in the preparation of samples, is less than $5 at this laboratory. This means that samples could be brought to such a laboratory, and four days later the results could be received as to the immediately available phosphate and potash, at a cost less than 50 cents per sample.

A method of soil analysis to be valuable, must be cheap and rapid. It is not enough to say that a soil is deficient in phosphate for example. It should be ascertained how deficient. If a soil analysis shows 10 parts per 1,000,000 of phosphorus pentoxide, and the intended crop requires 20, it is more reasonable to add the deficient 10 parts than to pronounce the soil deficient in phosphate and proceed to add the 20 parts which the crop will need. If a soil is totally deficient in every plant food, it is generally known that such a soil cannot be fertilized with profit. It is only where there is a partial deficiency, or a poorly balanced soil, that the use of artificial food is economy. In a true sense of economy, the agriculturist should know from the analysis supplied him, as to whether a full or partial fertilization is profitable. Suppose he finds his potash to be somewhat below the normal requirement, and his phosphate to be about half deficient. Will he supply the phosphate until it balances the potash, or will he increase the potash up to the normal, and balance the phosphate with that. In the first case it would be the equivalent of buying something in order to make something that he has, profitable, while in the second case he would be buying something which required the purchase of something else, in order to make either profitable.

In the study of the Rothamsted soils, the opportunity is offered to compare results obtained by the method as above proposed, and that published by Dyer in the *Journal of the Chemical Society*, 1894, upon the use of 1 per cent. citric acid as a solvent for available plant food. There are but four of the soils which were studied by Dyer, namely, pots 160, 164, 166, 168. His samples were taken to the same depth as those sent to the Department of Agriculture. The results are expressed in parts per 1,000,000 and compared with those obtained by the hydrochloric acid and the crops.

TABLE G.

Comparing one per cent. citric with N/200 hydrochloric acid.
[Parts per million.]

	Supposed available.		Taken off by crops.		
Pot.	P_2O_5.	K_2O.	P_2O_5.	K_2O.	Solvent.
160	1	22	4	24	HCl
160	60	20	..	..	citric
164	2	17	13	29	HCl
164	425	23	..	..	citric
166	1	160	6	30	HCl
166	81	407	..	..	citric
168	6	127	16	64	HCl
168	500	300	..	..	citric

In pot 160, a soil that is known to be impoverished in all plant food, the citric acid gives 60 parts per 1,000,000 as representing the available phosphate, an equivalent of 150 pounds per acre, figured to a depth of twelve inches, or as much as good crops of oats would take off in ten years. And in pot 166, another soil known to be totally deficient in available phosphate, the citric acid method shows 81 parts per 1,000,000, an equivalent of 205 pounds per acre, or enough for fifteen years. In the plots that have been fertilized with phosphate, pot 164 would be considered to have 425 parts or 1073 pounds per acre, and pot 168, 500 parts or 1264 pounds per acre, or the equivalent of a good crop feeding for seventy-five years. The total phosphorus pentoxide as obtained by Dyer on the unfertilized soil in pot 160, was equivalent to 2400 pounds per acre, while that on the fertilized soil of pot 168 was 4600 pounds per acre, these two plots being the same original soil. Here is an accumulation of over 2000 pounds of phosphorus pentoxide, of which very little can be available, it having reverted to an insoluble form. However, the citric acid is able to obtain 1200 pounds of this accumulation.

As has been previously referred to, these soils, where they have been fertilized, are so artificial that not much can be learned from a chemical study of them, pot 160 being the only unfertilized soil. In this pot the indications for the potash are very close, and agree with the crop data while in the phosphate there is a wide discrepancy.

It is recognized that this citric acid digestion was the first step toward using weaker solvents, and that the work was done seven years since. And to quote that writer's language, " since the choice of a solvent for use in soil analyses must in the end be empirical, both as regards its form and its strength," it is surprising that the tendency has been to work with citric acid, or acetic, oxalic, aspartic, or any complicated solvent of such a nature. Only last year the investigator of that same work on citric acid, addressed our Association of Agricultural Chemists and very aptly remarked that he saw no reason why its use should be discontinued, as nothing better had been suggested.

It is interesting to notice some of the conditions of solubility as used by Dr. Dyer, as well as many of the American chemists, on this line of work. According to Dr. Dyer's article, " the temperature ranged between 10° and 19° C.," the work being done in the winter season. The same line of investigation has been continued in this country in summer at "room temperature," which is oftentimes 30° to 35° C. Here is a range of 9° in the digestion as carried on by Dr. Dyer, and an extreme range of 25° in the continuation of the work. It may here be worth while to refer to some unpublished results obtained by Dr. W. G. Brown and myself, in reference to the controlling conditions of solubility in citric acid. The results are tabulated in Table H.

TABLE H.

Soil 29. 200 grams in citric acid.

Liters solvent.	Strength acid. Per cent.	Temp. digest. Degrees.	Time digest. Hours.	P_2O_5. Per cent.	K_2O. Per cent.
1	1	30	5	0.011	0.007
2	1	30	5	0.012	0.008
3	1	30	5	0.014	0.008
1	2	30	5	0.012	0.007
2	2	30	5	0.013	0.007
3	2	30	5	0.013	0.008
1	1	40	5	0.022	0.008
2	1	40	5	0.022	0.008
3	1	40	5	0.026	0.009
1	2	40	5	0.024	0.008
2	2	40	5	0.022	0.008
3	2	40	5	0.030	0.008

It is seen that in variations of 1 to 3 liters of solvent and 1 to 2 per cent. of acid, at a constant temperature of 30° C., the phosphorus pentoxide is constant at about 0.012 per cent. and the potash constant at 0.008 per cent. With the same conditions maintained, and the temperature increased by 10°, the phosphorus pentoxide is constant at about 0.024 per cent., and the potash remains 0.008 per cent.; that is to say, an elevation of 10° in temperature, doubles the solubility of the phosphate. An elaborate piece of research was undertaken to arrive at the strength of 1 per cent. which can at least be doubled without effect, while the extremely sensitive point, the temperature, was not considered. The potash conditions are different. It remains constant at 0.008 per cent., which exactly coincides with the result obtained with N/200 hydrochloric acid (see pot 29, Table F). Also in the unfertilized plots of the Rothamsted soils, in pot 160, Dr. Dyer obtained 20 parts per 1,000,000 against 22 by the hydrochloric acid, and in pot 164, 23 parts against 17, while in the fertilized plots, as pot 166 and 168, there were 400 parts against 160 and 300 against 127.

It is not intended that these references should undervalue the splendid work done by Dr. Dyer, but will suggest that the time has long since arrived for a second step to be taken in a line of work of importance, incomparable with anything else in scientific agriculture.

For the sake of comparison, the writer has selected a set of ten samples and subjected them to the several methods proposed for the determination of available phosphorus pentoxide and potash. The results are tabulated in Table I. They are arranged in the order of the agricultural value of the soils, as shown by the pot experiments, beginning with the better soil. The results are expressed as parts per 1,000,000.

TABLE I.

Comparison of proposed methods for available plant food.

[Parts per million.]

	P_2O_5.					K_2O.						
Pot.	N/5 HCl.	Ammonium citrate.	1 per cent. citric acid.	N/200 HCl.	Taken off by crop.	N/5 HCl.	Ammonium citrate.	1 per cent. citric acid.	NH_4Cl.	N/5 $CaCl_2$.	N/200 HCl.	Taken off by crop.
27	330	110	290	18	21	160	100	70	160	230	60	77
10	90	150	110	..	15	200	190	120	220	110	..	51
7	80	80	60	7	8	470	600	270	500	390	144	98
65	20	230	200	2	5	170	190	90	210	220	50	66
80	90	150	70	5	6	220	260	170	230	340	170	41
63	200	60	320	25	14	430	420	270	430	260	84	62
93	160	300	350	25	6	330	850	120	390	150	46	37
121	130	230	340	7	13	160	180	70	160	120	35	34
98	350	100	270	..	2	190	190	50	160	90	..	10
44	160	50	70	..	2	70	90	20	50	70	..	4

In the soil most deficient in phosphorus pentoxide, the lowest result obtained is 50 parts per 1,000,000, being double that obtained by the best crop grown in 175 beds, while the result in the highest soil is sixteen times greater than what it actually was in the pot. Pots 63 and 93 are highest in available phosphate, but it does not appear high in the crop, owing to the deficiency of potash in these soils. The N/5 hydrochloric acid method grades pot 98 as first, while it is actually last. It grades pot 93 about half that of the lowest, while it is the highest. The ammonium chloride method grades the highest pot, 93, first, but it grades one of the lowest pots, 65, second. The 1 per cent. citric acid correctly grades the highest pots, but grades the lowest as second. In the potash determinations, attention is called to the close agreement of the columns headed N/5 hydrochloric acid, and ammonium chloride. With the exception of those under the heading N/200 hydrochloric acid, the results in this table run from 10 to 200 times what it actually obtained in the crop, and in no definite direction.

Table E is incomplete owing to the lack of sufficient quantity of sample. In this table, in comparing pots 1 and 86, the phosphorus pentoxide is seen to be 105 against 74 in the N/25 acid. In the next weaker strength acid, the comparison is 63 to 40, then 35 to 26, then the figures reverse in N/200 and become 16 to 25. This last is just the result obtained by the crop. By a study of this table a number of such illustrations can be seen, which go to demonstrate that the fertility of a soil depends upon the quantity of phosphate contained in it, but upon the peculiar condition in which some part of that mineral exists.

By a comparison of Tables E and D, it was endeavored to obtain some foresight as to the successive crops. In cases where the soil is normally balanced in phosphate and potash, it will be seen that the phosphate represented as soluble in N/25 acid, very closely corresponds to that taken out by the three successive crops.

TABLE K.

Pot.	P_2O_5. N/25 HCl.	Yield of three crops.
7	20	18
14	24	21
19	48	49
22	50	12
25	16	11
27	60	57
29	13	14
76	57	60
85	44	28
86	74	68

In pot 7, three crops have taken out 18 parts of phosphorus pentoxide, and the result for N/25 acid is 20. In pot 14 three crops take out 21 parts, and the N/25 acid shows 24. In pot 19 the three crops take out 49 against the result 48 as shown, and so on through the others. Pots 1, 18 and 63 show abnormally high results in the N/25 acid. indicating an overbalance of phosphate.

While these results are not to be considered conclusive, yet, in the ten instances cited, the phosphate in all cases will be included within the phosphate soluble in N/25 acid, and in seven of these cases the results obtained by the three crops are practically identical with those obtained by the N/25 acid.

Special notice is directed to the fact that the proposed method as illustrated in Tables E and F, is intended as an interpretation of the yield of a crop, only in so far as the potash and phosphate are concerned. Two crops may make the same total yield of grain and straw, and still be very different in the amount of phosphate or potash that was taken from the soil. To illustrate, pot 162 in 1897 produced a crop analyzing 6.30 per cent. potash. Pot 164 in 1899 produced a total crop of the same weight as that in 162, analyzing only 1.35 per cent. potash. While pot 160 in 1899 produced a crop analyzing 0.31 per cent. phosphorus pentoxide, pot 164 in 1897 produced a crop analyzing 1.44 phosphorus pentoxide, the total crop weights being about the same. These pots are cited because they are the same original soil, the plots running high being fertilized. Here are crops the same in total yield, but one containing five times the plant food found in the other. We might refer to one crop as being diluted until it equals the other in weight. The question that presents itself is, Will a food so diluted be as valuable as an undiluted one, especially if the mineral matter is the desired constituent? If an animal is fed a ration of oats for the development of bone, on such a feed as that above referred to, it must eat five times as much, should it be fed on the poorer quality.

A crop deficient in the plant food desired, is a poor crop, even though large in bulk. While there are no instances recorded of where the price of oats was determined by its composition, rather than its bulk, still it is reasonable to infer that the one is more desirable than the other. If the soil is deficient in such a plant food, the deficiency should be supplied without regard to the effect upon the total yield. It is from this standpoint that the value of such a method may be viewed.

In order to obtain the efficiency of a soil in the matter of plant food supplied, the crop must not be looked upon as yielding so much grain, but the composition of the grain and straw must be taken together. The formation of grain is dependent upon the season. The soil may have supplied the needed plant food, and it may have been taken up by the plant, but the transmigration of that food throughout the plant, is a process confined to the functions of the plant, which is to a large extent determined by the season. A good season may be represented as where the greater portion of the plant food has moved into the grain, while in a poor season, just as much plant food may have been taken from the soil, but remained disseminated throughout the plant.

In pot 65 in 1895, the total crop ratio is 278, with phosphorus pentoxide expressed by a ratio of 5, while in pot 63 in 1897, the total crop ratio is 71, with phosphorus pentoxide equivalent to 15. The latter pot supplies a ratio of phosphate ten times that of the former.

It is evident that an overstimulated plant is quite different from the plant in its normal growth. The soil in pot 65. if not artificially, was naturally a very rich soil in nitrogen. The crop analysis shows 53 parts of nitrogen taken up, or nearly 20 per cent. more than the crop second highest in nitrogen of all the experiments that have been made in this work. Pot 63 in 1897 supplies three times as much phosphate, although it makes a total crop of but one-fourth that of pot 65. It would be expected that the crop in 65 was one in which the plant was enlarged with nitrogen-feeding, only that the ash is very high, showing that while potash and phosphorus pentoxide were taken in but very limited quantities, still some other mineral must have been substituted. However, these are "crude ash," and are very high in carbon, and not much can be learned from this.

In the Rothamsted soils the effect of fertilizer stimulant is apparent, even though none has been applied since received by the department. All except pot 170 had received nitrogen, pots 156 and 160 receiving nitrogen only. Pot 170, which had no fertilizer, shows a higher crop than 156 and 160. From a study of these soils it will be seen that the use of nitrogen increased the potash and phosphate but a trifle, while the addition of phosphate decidedly increased the phosphate taken up with no effect upon the potash. The addition of potash and phosphate shows a very large increase in both.

As before stated, the Rothamsted soils are so artificial that little reliance can be placed on them. These, with the previous indications, point to stimulated growth as being more probably a dilution of the plant in its other constituents as compared with the constituents in the applied stimulant, rather than being an increase of the normal composition.

If the available plant food can be looked upon from the position in which it is attempted to illustrate in this paper, there are many suggestions presented. In Table F, pot 1 shows 16 parts of phosphorus pentoxide available, and 16 parts taken up by the crop, while for the next crop, 8 parts were available and taken up, to say nothing of that taken out by the intervening buckwheat crop. In pot 7, 7 parts were available and taken up the first year, while the second year showed the same condition. In pot 19, 18 parts were available and taken up, though the next year showed 12 parts available and utilized. In pot 27, 18 parts were available and consumed; the second year showed 16 parts still available. In pot 31 the 16 available parts were taken up the first year, and 18 found for the next year. So with pot 63. While pot 76 shows 31 parts available with 29 taken up by its crop, still the following year 13 parts are found again available, and the same with other cases will be noticed. It is seen that there is a decided resemblance between the phosphate present for a first crop, and that for the succeeding one, and not the reverse condition; that is, if a small quantity is taken up by one crop it will be increased in the second crop, owing to an accumulation, and if a large quantity is taken up by a crop, the next crop will be deficient, owing to a preceding exhaustion.

From the very marked illustrations, it is easy to believe, first, that the mineral food which a plant does take up is that which existed in the soil in an assimilable form at the time of planting, and second, that in the course of the plant's growth, a fresh supply of food will be rendered assimilable for the use of a succeeding plant, and that large crops will provide large amounts of plant food for a future crop, and small crops can only provide small quantities for future use. Hence, small crops induce small crops, and large crops induce large crops to follow up to the point of exhaustion.

It will be noticed that but little emphasis has been placed upon the total crop, and that it is the absolute amount of potash and phosphate removed which is considered. The writer has not been able to establish any relation between a crop and its composition, the ratios of phosphorus pentoxide to its respective crop varying as from $^1/_{580}$ to $^1/_{50}$.

Crops may be likened to poor and fat animals, the former having just as much mineral matter as the latter, while the total weights vary greatly. It is suggested that a crop obtains that quantity of mineral matter which is available, irrespective of an abundance or deficiency of nitrogen, the nitrogen increasing the weight through the additional formation of starch and such substances, and that the additional weight due to such carbohydrates, is much more subject to climatic influences than is that of the mineral constituents.

An effort was made to get some definite insight as to the changes which a soil must undergo, when subjected to the action of plant roots, and, if possible, to locate the changes at regular intervals. Such a condition is more easily seen when a minimum amount of soil is acted upon by a maximum amount of roots, and where the growth is forced, as in greenhouse culture. Accordingly, 40 pots, holding about 1 pint each, were filled with the same soil, and in each pot, 18 grains of corn were planted. At the end of two weeks, 6 pots were emptied, the corn plants and their roots freed of soil, all the soil put together as one sample, and all the plants and roots made into one sample. The roots were separated very easily, washed in a minimum quantity of water, the washings concentrated and mixed through the soil, which was then allowed to assume an air-dried condition before its moisture-free weight was obtained. The corn plants with their roots were then ashed and analyzed. The period at the end of the first two weeks will be known as B. After B, the periods were made weekly, the same operation of separation being repeated, until periods C, D, and E, had been reached. Here the plants had become pot-bound, and ceased to advance.

The original soil is designated as A. A sample of the corn seed used was analyzed in order to make the correction for the plant food added through this source. The plants and roots analyzed practically the same percentage of phosphate for each period. In no instance was all the phosphate recovered that had been added in the form of seed, about $^1/_{16}$ of it being left. In potash, however, there was an increase as 2, 4, 6, 6, until about four times as much had been taken from the soil as had been added in the seed.

In the soil analysis, the conditions of digestion were those as previously described, with the strength of acid ranging from N/200 to 2N. The results are tabulated in Table L.

A is the original soil, B the condition after a two weeks' growth, C a week later than B, D a week later than C, and E a week later than D. At B, there had been an addition of 23 parts of phosphorus pentoxide per 1,000,000 to the soil, as shown by the analysis of the plants and roots, while 60 parts of potash had been taken from the soil. At C, D, and E, the condition of the phosphate remained unchanged, while the potash increased to 130, then 225, after which the growth of the plants ceased, as shown by the potash remaining constant also the next period.

Period D will then be corrected for phosphorus pentoxide by subtracting the 20 parts which had been left from the seed, while the potash will be corrected by the addition of 225 parts, this much being taken up in excess of that which was added in the seed. Now if the original condition as shown in A be subtracted from the condition as shown in corrected D, it will leave a gain at the D period, which represents the transition of plant food into a more soluble state, in the course of four weeks under these most extreme conditions. After D, the plant's vitality was exhausted, and there is shown a shifting of the plant food in the reverse direction. There is evidence of a reverting, or fixation. At period E, there was no advancement over D, as shown by the phosphate and potash which was taken up. E is corrected, as was D, when there is found to be a loss over the original condition A, in phosphate, and a gain in potash. However, the potash gain has descended since the D period, so the difference in the conditions of potash at the periods D and E, represents a loss, while in phosphate, the gain at D, plus the loss at E, represents the transition of phosphate in a reverse direction. Still there is a total gain over all, represented by the transition of 22 parts of phosphorus pentoxide and 182 parts of potash into the range of solubility of 2N acid.

This points to a condition as existing in a great state of instability, though with a definite trend. It is a condition wherein the mineral compounds are constantly undergoing a change into

TABLE L.

Periodic effects of plant roots on the soil.

[Parts per million, soluble in HCl.]

	P_2O_5.									K_2O.										
	N/200.	N/100.	N/50.	N/25.	N/10.	N/5.	N/2.5.	N.	2N.	N/200.	N/100.	N/50.	N/25.	N/10.	N/5.	N/2.5.	N.	2N.	Gain of P_2O_5.	Loss of K_2O.
A	7	12	27	40	81	185	271	350	452	98	121	137	148	160	177	184	204	228	..	..
B	10	16	42	70	..	..	..	..	..	105	132	158	170	..	..	..	..	..	23	60
C	12	22	53	64	108	..	..	..	..	85	107	128	144	156	..	..	..	..	24	130
D	12	21	53	73	128	219	304	410	516	59	81	86	110	129	145	150	170	194	20	225
E	9	16	34	56	88	161	238	334	494	15	53	75	89	102	126	131	154	185	20	225
Corrected D	..	..	33	54	108	200	284	390	496	..	..	..	335	354	370	375	395	420	..	..
Gain at D	..	..	6	14	27	15	13	40	44	..	..	..	187	193	193	191	191	192	..	..
Corrected E	..	..	14	36	68	141	218	314	474	..	..	..	314	327	351	356	379	410	..	..
Loss at E	..	..	13	4	13	44	53	36	..	Gain at E		..	166	167	174	173	175	182	..	..
Total loss	..	..	19	18	40	59	66	76	..	..	..	..	21	26	19	19	16	10	..	..
Actual gain	..	..	..	..	..	..	..	..	22	..	.	..	..	..	..	..	..	182	..	..

more soluble compounds, and with a tendency to revert before the compounds reach the point where they would leach out in drainage water.

It is not seen how so great a change in the solubility of minerals can be brought about through so weak an acid as is contained in the sap of plants. In this case, a five weeks' growth so affected the more insoluble minerals as to bring 182 parts per 1,000,000 of the potash compounds into the range of solubility of 2N acid. As a mere question of solution, the weak acid of the sap could not possibly exert so strong a solvent effect as that shown. It is easier to believe that the changes in the mineral compounds of the soil are due to the action of bacteria, which are stimulated by the excretions from the roots. On such a basis it would be easier to account for the benefit obtained, by the rotation of crops, and conclude that a good season meant nothing more than a sufficiency of moisture and warmth, in which such bacteria flourish.

The complete chemical and mechanical analyses, as illustrated in Tables B and C, have no bearing on the immediately available plant food, in so far as the writer is able to interpret. They have been studied from almost every conceivable point, and for every definite conclusion drawn, an equally indefinite one may be found under similar conditions. The analyses are presented in order that the work may be as complete as possible, and perhaps aid another who may care to study the data here presented.

In Table M, the order of descending magnitude, according to crop production, is continued.

In column *a*, the comparative producing ability is ascertained, according to the potash, lime, phosphorus pentoxide and nitrogen, being arranged in serial order up to 34. This order is obtained by taking the average grade of each soil in the four named determinations; that is, the soil in pot 1 stands first in potash, tenth in lime, eleventh in phosphorus pentoxide, and sixth in nitrogen, or an average of seventh, which, compared with the remaining soils, makes it rank fifth in serial order. In the same manner are the rest of the figures representing the serial order obtained.

In column *b*, a similar order is obtained, based on the standing in potash, phosphorus pentoxide and nitrogen.

In column *c*, potash and phosphorus pentoxide.

In column *d*, potash and nitrogen.

In column *e*, phosphorus pentoxide and nitrogen.
In column *f*, potash only.
In column *g*, phosphorus pentoxide only.
In column *h*, nitrogen only.

TABLE M.

Serial order based on the comparative value of

Pot.	K_2O. CaO. P_2O_5. N. *a*	K_2O. P_2O_5. N. *b*	K_2O. P_2O_5. *c*	K_2O. N. *d*	P_2O_5. N. *e*	K_2O. *f*	P_2O_5. *g*	N. *h*	Complete analysis. *i*	Crop.
76	5	2	6	1	8	1	18	7	13	1
27	25	27	25	26	23	25	19	26	26	2
7	11	8	15	3	16	5	26	6	11	3
16	22	21	24	17	14	23	20	11	20	4
90	18	20	18	21	15	22	11	21	25	5
18	4	3	4	8	5	4	6	12	14	6
5	12	9	14	4	13	9	22	5	10	7
74	10	11	23	10	11	17	24	2	4	8
65	14	13	16	12	19	11	21	13	1	9
80	30	30	31	30	30	31	30	24	29	10
14	28	28	32	24	29	32	31	15	30	11
22	8	7	12	9	4	15	13	4	19	12
9	7	6	7	6	3	12	9	3	15	13
70	2	5	5	5	1	14	5	1	3	14
3	31	31	30	31	31	28	29	29	27	15
25	32	33	33	33	32	33	33	28	33	16
19	21	16	8	19	7	21	4	16	22	17
12	20	25	26	23	18	30	16	17	18	18
51	26	26	13	29	24	19	12	34	28	19
87	24	23	17	25	23	18	15	30	23	20
39	15	14	21	14	10	20	17	9	16	21
63	9	15	4	20	22	6	10	33	2	22
69	29	29	28	27	28	29	28	23	31	23
73	17	18	22	13	17	16	23	10	17	24
84	3	4	1	7	6	2	7	14	12	25
29	27	25	20	28	21	26	8	27	21	26
31	13	17	10	18	20	13	14	22	6	27
89	34	34	34	34	34	34	34	31	34	28
1	1	1	2	2	2	8	2	8	5	29
85	23	19	9	22	12	24	3	20	24	30
104	16	12	11	11	24	3	25	18	9	31
93	6	10	3	13	9	10	1	19	7	32
101	33	32	29	32	33	27	32	32	32	33
35	19	22	19	16	27	7	27	5	8	34
First half	9	9	9	9	11	8	5	12	8	
First third	4	5	2	5	3	5	2	5	4	
First fourth	2	3	2	4	2	4	1	4	2	

In column *i*, the serial order is based upon the complete mineral analysis.

When every mineral is taken into consideration, it is very evident that the soil ranking first in serial order will be the one with the largest amount of mineral matter dissolved, which is to say, that the soil lowest in insoluble residue will rank first in serial order. Accordingly column *i* is obtained direct from the column headed "Insoluble Residue," in Table B.

If these averages are arranged in two divisions, the serial order up to 17 should be found in the first division, in order that they may agree with the actual productive capacity, whereas, upon inspection, it is found that in every instance but half as many are found in the first division as should be there theoretically. If arranged in three divisions, the first division should contain eleven, ranging from eleven down. However, those found in the first division that come within this range, vary from one-fifth to less than one-half of the theoretical number. Again, if arranged in four divisions, in the first should be found eight, ranging from that figure downward, whereas, there is found but from one-fourth to one-half of the theoretical number.

At the bottom of the table are found the number that are found in each column in the first half, first third, and first fourth respectively.

The only deduction that can be obtained from this, is that the figures are remarkably adverse to the conclusion desired, as is well illustrated in pot 1 (which will undoubtedly rank first), according to all of the standards suggested in this table, while it grades but one-third of the maximum crop. The pot ranking lowest, will be unquestionably pot 89, when it is seen that the lowest and highest are consecutive, the lowest preceding.

It is believed that no such collection of complete analyses, on such a variety of soils whose agricultural value has actually been determined, has previously been presented, and that it would be difficult for them to be shown in a more unfavorable light. However, many such analyses are made, and in some cases even the mineral matter insoluble in acid is determined by means of fusion.

Such analyses might be of value in determining the geological origin, but this could be better done by an examination of the rock, in the case of sedentary soils, whereas in the case of transported soils it could not be done in either case.

If it is expected that the digestion in strong acid will reveal what is to be the future state of fertility, it is suggested that the effect of weathering, upon this insoluble mineral matter, is so infinitesimal that it would be out of consideration in so far as agricultural purposes are concerned.

It will not be overlooked that the discussion throughout this paper, pertains to the oat plant only. As to whether the oat plant's habits and requirements of the oats are comparable with those of another plant, or whether the conditions of every plant must be established independently, is not within the scope of this paper. On lines similar to those followed in this paper, it would be possible to establish solvent conditions as representing the feeding ability of any plant. whereupon the desired crop would be specified when the soil sample is forwarded for analysis. If a diagnosis of a soil is made, it must be with reference to a specified plant, as plants vary so in the nature of their feed, and their ability to obtain it.

If plant food can be identified by a laboratory method, there is no doubt as to a method of procedure in the taking of soil samples from the field. A succession of similar depths should be taken in order to ascertain how deep the available food existed, and with this, compare the depth to which the feeding roots of the intended crop are known to penetrate. For actual practice, the writer has constructed a very simple form of sampling cylinder, made out of 7-inch wrought-iron pipe. The pipe is cut 6 inches in length, and turned down to a thickness of $^1/_{16}$ inch, leaving a collar on one end, to strengthen and drive upon, while a cutting edge is turned at the other end. This makes a strong cylinder weighing about 4 pounds. The cylinder is driven down to the top, and the enclosed soil taken out. The soil is dug from around the sides of the cylinder as it is driven down for the second 6 inches, and so for a third 6 inches. The separate portions are weighed and subsampled for analysis, and from such data the pounds per acre of plant food to definite depths are obtained.

It is clearly obvious that the depth to which the plant food is supplied to the plant, is of great importance. To fix a definite depth at which a soil should be sampled, is about the same as attempting to fix a definite depth at which a plant shall feed. If the first 6 inches of one soil should contain, say 20 parts per 1,000,000 of available phosphorus pentoxide, and the second 6 inches should contain none, and in a second soil the first 6 inches should contain 10 parts, and the second 6 inches also 10 parts, it is reasonable to suppose that in the growth of plants, which will feed to a depth of 12 inches or more, two such soils will be equally fertile.

The more divisions into which a soil sample can be divided, the more data there will be for study. If the successive depths could be reduced to 3 or 4 inches (it being understood that definite areas are taken), and a series of samples taken until the vanishing point of the available food is reached, from such data a curve could be drawn which, if compared with the root system of a plant, would illustrate the amount of available food which could be assumed as being present.

However, if it is limited to two, or even one sample, let the total depth be that to which the intended crop is known to feed. If it is intended to estimate the amount of plant food which is in an acre to the depth of a feeding crop, say 12 inches, and all of the available food chances to be in the first 4 inches, it is immaterial as to whether the soil be sampled to a depth of 4, 6, 8, 10, or 12 inches, as the final calculation will be the same in each case. Consequently, if it is not known to what depth the available food exists, if a single sample to the depth of 12 inches be taken, it covers all doubt, and with no disadvantage in case the available food does not extend so far.

For an illustration, Table N is an arrangement of the first and second 6 inches of the same soil, with the phosphorus pentoxide and the potash of the upper and lower samples arranged accordingly.

In soil *a* the first 6 inches were in pot 1, with the second 6 inches in pot 31, the others being similarly arranged. The phosphorus pentoxide in soils *a* and *d* is seen to be equally distributed to at least a depth of 12 inches, while in soils *c* and *f*, practically all of the phosphorus pentoxide is found in the first 6 inches. In soils *b* and *e*, there is practically none in the first 6 inches, and, as would be expected, none in the second 6 inches.

If it is undertaken to place a comparative value on these soils with respect to the phosphorus pentoxide, let it first be assumed

TABLE N.

Surface soils and their respective subsoils compared.

[Parts per million.]

Soils.	Pot.	P_2O_5.	K_2O.
a	1	16	65
	31	16	20
b	3	2	102
	35	1	1
c	19	18	235
	51	3	76
d	63	25	84
	93	25	6
e	69	1	47
	101	1	31
f	86	25	116
	115	1	16

that the intended crop can not feed to a greater depth than 6 inches. Then soils *a* and *c* are equally fertile, as will be also *d* and *f*. If it is assumed that the intended crop will feed to at least a depth of 12 inches, the soil *a* will be one-half more fertile than *c*, while *d* will be two times as fertile as *f*, soils *b* and *e* being deficient in both cases.

Similar comparisons may be made with the potash.

In the continuation of soil study, assume that the available plant food rarely extends to a depth of more than 12 inches, and that plants penetrating below that depth, do so for the purpose of obtaining moisture. If such assumptions should become facts, it would be a simple matter to obtain an accurate sample by sampling through a definite area to a depth of about 12 inches, weighing the total sample, mixing and taking a definite portion as a subsample for analysis. In such a case, the exact depth to which a sample is taken would be of small importance. It might range from 10 inches to 10 feet without variation in the result, provided the area over which the sample is taken, is accurately defined, and a definite portion of the thoroughly mixed total sample taken.

TABLE O.

Index of samples studied.

Pot.	State.	Type.	Strength sol. for N/10 filtrate.	Pot.	State.	Type.	Strength sol. for N/10 filtrate.
1	California	vir. sur.	N/8.5	73	Indiana	cul. sur.	N/7.4
3	Illinois	"	N/9	74	Iowa	"	N/6
5	"	"	N/7	76	Kansas	"	N/8.4
7	Kansas	"	N/8.3	80	Michigan	"	N/9
9	Indiana	"	N/7.2	84	Montana	"	N/6.1
12	Massachusetts	"	N/8.7	85	New York	"	N/9.6
14	Michigan	"	N/9	86	Oregon	"	N/8.5
16	Missouri	"	N/8.5	87	S. Dakota	"	N/6.6
18	Montana	"	N/8	89	Texas	"	N/9.4
19	New York	"	N/9.1	90	Wisconsin	"	N/8.8
20	Oregon	"	N/8.4	93	California	cul. sub.	N/6.6
22	S. Dakota	"	N/8.4	101	Illinois	"	N/9.1
25	Texas	"	N/9	104	Kansas	"	N/9.2
27	Wisconsin	"	N/8.2	115	Oregon	"	N/6.5
29	Maryland	"	N/9.5	117	"	"	N/6.1
31	California	vir. sub.	N/6.3	156	Rothamsted	W10*a*	N/6.2
35	Illinois	"	N/8	158	"	W11	N/6
39	Iowa	"	N/6.3	160	"	B1*a*	N/6.7
51	New York	"	N/9.3	162	"	W13	N/6
63	California	cul. sur.	N/6	164	"	B2*a*	N/6.7
65	"	"	N/9.5	166	"	B3*a*	N/6.7
69	Illinois	"	N/8.5	168	"	B4*a*	N/6.7
70	"	"	N/5.5	170	"	W3	N/5.4

NEW BOOKS.

METHODS OF CHEMICAL ANALYSIS AND FOUNDRY CHEMISTRY. BY FRANK L. CROBAUGH, M.S., Cleveland, O. Published by the author.

The analyst, or any person who intends to become an expert analyst, needs to have his methods at hand concisely stated, with all details verified by himself or by an author who has tested the methods thoroughly. In a work recently published by Mr. Frank L. Crobaugh, of Cleveland, Ohio, may be found a collection of selected methods especially in use in analysis of iron and steel, which have been thoroughly tested by the expert hand of the author. On account of the varied experience of Mr. Crobaugh in iron laboratories, in iron and steel plants and in his own business, his compilation of these methods will be of great service to any chemist engaged in similar work.

In Part II of this work will be found a more complete statement of the principles and methods of foundry chemistry, than can be found elsewhere. Foundrymen are beginning to appreciate the importance of a more thorough knowledge of the chemical composition of pigs and castings, and of the chemical changes involved in foundry practice. They will find this book very useful in their daily work.

C. F. MABERY.