LXIV.—*The Effects of the Growth of Plants on the amount of Matter removed from the Soil by Rain.*

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In a paper which I read last year before the Society, I gave an account of experiments which showed the influence exerted by the growth of plants in a soil on the drainage-water from that soil. In those experiments the composition of the water which flowed from soil 4 inches deep, and in which clover was growing, was found to be greatly different from that which flowed from the same soil, but in which there was no vegetation. The amount of solids removed was 12·5 grams (48 grains per gallon) from "clover soil," and 50 grams (220 grains per gallon) from the "blank."

During the past season I have repeated the experiments, but using in the place of shallow pans large glazed stoneware pans, 18 inches broad, with perpendicular sides 10 inches high, and provided with a hole at the bottom, from which the drainage-water flowing was collected in jars placed below.

In these pans were placed 100 lbs. of soil, which, when beaten down, filled the pans up to 1 inch of the top, leaving a clear 9 inches for the growth of the plants. The following is an analysis of the soil:—

Moisture	5·06 per cent.	
Calculated on the dry soil—		
Soluble salts (containing sulphates and traces of chlorides)	0·680	„
Organic matter	11·80	„
(Containing nitrogen equal to ammonia)	0·436)	„
SiO ₂	24·54	„
P ₂ O ₅	1·185	„
CaCO ₃	53·98	„
Al ₂ O ₃	3·065	„
Fe ₂ O ₃	3·84	„
MgO	0·58	„
K ₂ O	0·451	„
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Owing to the delay experienced in obtaining the kind of pan which I desired, I decided to repeat the same experiments as last year in

shallow pans, holding only 28 lbs. of soil (depth of soil 4 inches), which had been coarsely sifted: therefore on May 4th I sowed in No. I clover seeds, and No. II was left "blank."

It was not until late in the season that I was able to sow seeds in the large pans, but on June 18th there was sown in No. 3 cabbage seed; in No. 4, wheat; in No. 5, beans; in No. 6, "cow-grass" (common perennial clover); in No. 7, garden turnips; and No. 8 was left blank. All the pans were placed in a moderately sheltered spot, and surrounded by a spacious wire cage, so as to exclude birds, leaves, &c.

As the season was favourable, the plants flourished up to the date when it was considered necessary to discontinue the experiment, and, with the exception of the wheat and turnips, all reached maturity, and the growth of the clover had been strong enough to allow of a crop being taken off.

When it appeared that the plants were suffering from drought, equal quantities of distilled water were poured upon them evenly, and this water amounted altogether to 2 gallons (9 litres). The drainage-water which had collected in the jars below the pans, and had been from time to time evaporated in basins nearly to dryness, amounted in the case of No. I, to 20·26 litres; No. II, to 24·54; No. 3, to 10·91; No. 4, to 14·90; No. 5, to 11·97; No. 6, to 9·12; No. 7, to 18·95; No. 8, to 14·95. The plants were wholly removed from the soil on September 21st, and during the interval, May 4—September 21, 16·2 inches of rain = 14·87 gallons, and during the interval, June 18—September 21, 14·7 inches of rain = 13·529 gallons had fallen; to this quantity the 2 gallons of distilled water must be added, making therefore a total "rainfall" of 18·38 inches (16·87 gallons = 76·45 litres), and 16·88 inches (15·529 gallons = 70·56 litres) respectively.

The drainage-water when evaporated yielded, in each case, of solid matter:—I, 7·092 grams; II, 25·576; (3), 5·039; (4), 6·463; (5), 6·942; (6), 5·422; (7), 7·024; (8), 12·862.

The plants, after careful cleansing so as to remove as far as possible all adhering soil, which was found to be most difficult, as the fine fibres persistently retained a certain portion of soil, yielded on ignition the following amount of ash:—

I = 21·32 grams; 3 = 3·53; 4 = 8·05; 5 = 10·42; 6 = 18·503; 7 = 3·69.

During the evaporation of the water, a small amount of organic matter separated out, and this being different in each case, as regards quantity and colour, affected the appearance of the dry residues, which were of varying shades of pale reddish-brown, and very deliquescent.

The following Table I shows the amount of solid matter removed from each sample of soil by the drainage-water, the total ash of the

crops, &c. In the fourth column will also be found the amount of solid matter removed per gallon of drainage-water, the mean quantity obtained from 3, 4, 5, 6, and 7 being 34 grains per gallon, a quantity not widely differing from that obtained by Völcker in 1866—69, viz.,

TABLE I.

Plants.	Drainage-water, in litres.	Solid matter in drainage-water, in grams.	Solid matter in drainage-water, in grains per gallon.	Total dry matter of crop, in grams.	Total ash in crop, in grams.	Total solids removed from soil by drainage-water and crop, in grams.	Development of crop.
I. Clover .	20·26	7·092	24·500	121·90	21·32	28·412	Very strong.
II. Blank .	24·54	25·576	73·11	—	—	25·576	—
3. Cabbage	10·91	5·039	32·39	30·64	3·53	8·569	Poor.
4. Wheat .	14·90	6·463	30·43	41·86	8·05	14·513	Strong and healthy, blos- som barely reached.
5. Beans . .	11·97	6·942	40·68	138·24	10·42	17·364	Very healthy strong pods, well formed.
6. Clover . .	9·12	5·422	41·703	134·37	18·503	23·925	Very strong and healthy.
7. Turnips	18·95	7·024	26·00	22·01	3·69	10·714	Poor, leaves healthy and developed, bulbs not so.
8. Blank . .	14·95	12·862	60·451	—	—	12·862	—

33·3 grains per gallon, from unmanured fields in which wheat was growing. Table II shows the amount of all the constituents present in the drainage-waters in grains per gallon, and the percentage composition of the total solids removed by the water from the soil; and in III will be found the absolute quantities of each of the several constituents.

TABLE II.

	No. I. Clover.		No. II Blank.		No. 3. Cabbage.		No. 4. Wheat.	
	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.
Loss on ignition	26·06	6·384	15·82	11·566	13·89	44·990	13·91	4·233
SiO ₂	7·02	1·719	2·93	2·142	10·85	3·514	3·68	1·119
Cl	3·93	0·9628	6·08	4·445	0·52	0·1694	0·57	0·1734
SO ₃	13·45	3·295	18·56	13·569	7·90	2·558	14·50	4·412
CO ₂	16·50	4·0425	0·96	0·7018	19·46	6·3028	20·40	6·207
P ₂ O ₅	2·85	0·702	2·78	2·0324	3·05	0·988	1·19	0·3621
Al ₂ O ₃	3·45	0·7962	1·67	1·2209	4·64	1·725	1·88	0·5721
Fe ₂ O ₃	0·96	0·2362	0·58	0·424	0·51	0·1502	0·30	0·9129
CaO	30·13	7·3778	12·84	9·387	34·50	11·430	36·02	10·961
MgO	2·37	0·5806	2·62	1·184	3·15	1·0203	4·23	1·287
K ₂ O	1·82	0·4459	6·64	4·8544	5·24	1·697	3·76	1·144
Na ₂ O	6·97	1·6076	15·02	10·981	6·07	1·966	3·08	0·937
NH ₄	0·83	2·4426	2·08	1·5206	1·10	0·3562	0·48	0·1476
N ₂ O ₅	9·97	0·2073	28·06	20·5147	1·54	0·4998	7·24	2·200

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	No. 5. Beans.		No. 6. Clover.		No. 7. Turnips.		No. 8. Blank.		Average percent- age composition of solid matter in drainage from 3, 4, 5, 6, 7.
	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.	Per cent. of solid matter.	Grains per gallon.	
Loss on ignition	6.72	2.745	19.80	8.257	11.03	2.868	16.93	10.234	13.07
SiO ₂	1.94	0.7926	4.36	1.818	10.59	2.7534	6.82	4.123	6.28
Cl	0.90	0.3677	1.74	0.7356	0.15	0.039	0.85	0.5138	0.77
SO ₃	10.43	4.262	9.07	4.672	14.31	3.6206	11.14	6.7342	11.24
CO ₂	22.10	9.0902	14.28	5.945	14.53	3.7778	7.84	5.0394	18.15
P ₂ O ₅	0.73	0.298	1.15	0.4796	2.16	0.5616	1.70	1.0276	1.65
Al ₂ O ₃	0.07	0.0286	0.51	0.2127	3.32	0.8632	2.77	1.6745	2.08
Fe ₂ O ₃	trace	trace	0.43	0.179	0.58	0.1508	0.34	0.2055	0.36
CaO	30.36	12.403	26.75	11.155	24.48	6.365	26.83	16.418	30.42
MgO	1.18	0.482	3.32	1.384	3.54	0.9204	3.15	1.9042	3.12
K ₂ O	4.60	1.871	4.38	1.8266	4.18	1.0868	5.96	3.6029	4.43
Na ₂ O	2.32	0.9479	2.70	1.126	3.00	0.7800	2.66	1.6080	3.43
NH ₄	0.89	0.3579	0.93	0.3868	0.55	0.143	0.34	0.2055	0.79
N ₂ O ₅	1.60	0.6468	24.35	10.1546	2.50	0.533	24.87	15.034	7.44

From the figures in Table II it will be seen that all the crops prevented relatively the removal of a considerable quantity of soluble material; and not only relatively was this removal prevented, but also absolutely, as reference to Table I shows, in which it appears that the solids removed from "blank" are nearly double in weight of those removed from some of the pans, viz., 12·8 and 7 grams, and at the same time, with one exception, the percolation was the highest.

Comparison of the *weight* of the ash of the crops with that of the solids removed by drainage appears to indicate that those plants which remove most material in their ash, also cause a large amount of matter to become soluble in the soil (in addition to what they are capable of absorbing), and in consequence to be lost:—

	Turnips.	Beans.	Wheat.	Clover.	Cabbage.
Soluble matter in drainage-water, grams....	7·024	6·942	6·463	5·422	5·039
Ash of crop, grams....	3·690	10·420	8·050	18·500	3·530
Percentage of ash in plants	16·800	7·550	19·250	13·770	11·520

Clover and turnips are an exception to this statement, which is founded on the slenderest basis, and is consequently untrustworthy; for not only is the number of experiments insufficient for the foundation of such a theory, but also the separation of adhering soil, as before stated, was most difficult; and more especially was this found to be the case when preparing the wheat plants for analysis, the root-lets having ramified through the whole soil, rendered the percentage of ash very high, 19 per cent. (containing 56 per cent. SiO_2).

There was much less difficulty experienced in freeing the roots of the other plants from soil, therefore I believe that the figures representing the total ash of these plants are approximately correct, whereas the ash of the "wheat" should be much lower.

Comparison of Tables III and IV does not show any definite relationship to exist between the composition of the substances removed by drainage and by the plants; still, taking into consideration only the most important ash-constituents, it is possible that we here have indications (though quite as slight as those above referred to) of some relationship between the loss experienced by the soil through drainage, and the loss due to the plants. When a plant removes much of a certain substance, that substance appears in smaller quantities in the drainage, and this is what is to be expected. Seeing, however, that this statement is contradictory to the former one made concerning the weight of the total solids in the drainage-waters, it should be pointed

TABLE III.—*Absolute Quantities removed by Water from Soil (in grams) calculated from Tables I and II.*

	I. Clover.	II. Blank.	3. Cabbage.	4. Wheat.	5. Beans.	6. Clover.	7. Turnips.	8. Blank.
Loss on ignition	1.8481	4.0461	0.6999	0.8990	0.4665	1.0735	0.7747	2.1775
SiO ₂	0.498	0.7493	0.5468	0.2378	0.13467	0.2364	0.7403	0.8862
Cl	0.2787	1.5550	0.0262	0.0368	0.0625	0.0913	0.01053	0.1123
SO ₃	0.9539	4.7469	0.3981	0.0937	0.7240	0.4917	1.0051	1.4328
CO ₂	1.1702	0.2455	0.9807	1.3184	1.5341	0.7742	1.0206	1.008
P ₂ O ₅	0.2021	0.7110	0.15369	0.0668	0.05067	0.06225	0.1517	0.2186
Al ₂ O ₃	0.2146	0.4271	0.2338	0.1215	0.00486	0.0276	0.2332	0.3563
Fe ₂ O ₃	0.0681	0.1483	0.0257	0.0194	trace	0.0233	0.0407	0.0437
CaO	2.1368	3.2839	1.7384	2.3279	2.1076	1.4508	1.7195	3.4503
MgO	0.1681	0.6702	0.1587	0.2146	0.0819	0.1800	0.2486	0.4050
K ₂ O	0.1291	1.6982	0.2141	0.2831	0.3193	0.2375	0.2936	0.7664
Na ₂ O	0.4953	4.8415	0.3058	0.1991	0.1610	0.0146	0.2107	0.3421
NH ₄	0.0588	0.5319	0.0554	0.0601	0.0619	0.0542	0.0386	0.0437
N ₂ O ₆	0.7071	7.1766	0.0786	0.4679	0.1110	1.3202	0.1756	3.1987

out that the increase of some of these solids is probably due to the root-action, producing carbon dioxide in larger quantities, and to the greater amount of nitrification which has apparently taken place in some cases than in others. Further experiments are therefore required to determine whether the solvent action produced by carbon dioxide and by nitrification preponderates over the absorption by the plant of the soluble material produced, or whether the opposite is the case. But as regards the nitric acid in the water, the case seems to be reversed, for we find that from those soils on which the more nitrogenous plants were growing, a greater amount of nitric acid passed away in the drainage.*

TABLE IV.—*Amount of principal Ash-Constituents removed by Plants (in grams.)*

	3. Cabbage.	4. Wheat.	5. Beans.	6. Clover.	7. Turnips.
SiO ₂	0·1107	4·5112	0·4231	1·1749	0·0952
P ₂ O ₅	0·4977	0·41377	0·8086	1·5760	0·5088
CaO	0·3671	0·4508	0·9419	3·7006	0·0786
MgO	0·0604	0·4395	0·2136	0·5292	0·1144
K ₂ O	0·9263	1·1068	3·4050	4·4388	0·9882

As might be expected, potash and phosphoric acid are not eliminated in the same quantities as from the "blank," and nitric acid, a most essential plant-food, is comparatively speaking removed in but small quantities when plants are growing; this is, however, not found to be the case with "clover," for there we find about half as much nitric acid appearing as from the "blank;" this peculiarity is not shared to such an extent by the drainage-waters from the shallow pans I and II, but reference to last year's experiments shows that the residues from "clover" drainage contained 1·65 grams, and those from the "blank" 6·65 grams N₂O₅. We may therefore assume that although clover assimilates a large quantity of nitrogen, yet the influence of its growth is to cause the oxidation of a considerable amount of nitrogen in the

* Owing to circumstances which have prevented the full carrying out of the analysis as I had wished, I am unable to give the remaining ash-constituents and the nitrogenous matter present in the plants; being able to employ only approximate figures representing the composition of the whole plant, I prefer only to arrange the plants firstly in order of their richness in albuminoids, commencing with the maximum, and to compare this order with that in which they are arranged according to the nitric acid in the drainage-waters. In the first order will stand clover, beans, wheat, turnips, cabbage; in the second, clover, wheat, turnips, beans, cabbage. It will be seen that "beans" form the only exception, the others falling into their respective places.

soil, which nitrogen is not retained. This excess of soluble nitrogen may be due, as Dr. Völcker has suggested, to the continuous decay of parts of the plant, the dead parts which fall on the soil, yielding up their nitrogen to that soil, and Dr. Völcker has shown that a larger supply of soluble nitrogen is produced in the soil when a clover crop has been cut and allowed to grow again, than when the crop remains in the soil without cutting. It will be remembered that a crop was taken off the "clover."

That some of the drainage-waters should be richer in carbonates when plants are growing, is scarcely a cause for wonder, and must be due to the elimination of carbon dioxide by the roots of the plant, and is probably dependent to *some extent* on the root surface. The wheat possessed, as far as could be judged without actual measurement, the largest root surface, and we find that from the soil in which it grew there was removed (with the exception of "beans") the maximum amount of carbonates. It will also be found on reference to II that the percentage of carbonates present in the dry residues is far higher when plants are growing than when the soil is bare.

I might also point out the fact that sulphates are present in greater proportion in the water which passed from beans, clover, and turnips, and these are the crops which are supposed to require sulphates for their better development.

Potash, as before mentioned, is retained to a certain extent, and if the soil had been deeper the quantity eliminated would most likely have been considerably reduced. The same reason will account for the large amount of ammonium compounds (*vide* Table III, pan II, and in 1880 "blank" yielded 1.45 grams); but that there should be a larger quantity passing away when the soil supports life than when there is nothing growing in the soil (*see* 3, 4, 5, and 6), I cannot as yet explain. Possibly it is due to the non-retention of potash, for an increase in potash seems to be accompanied by an increase in ammonia; now it is known that the addition of a solution of potassium salts causes the removal of ammonia compounds from a soil, and in the cases in question we have an excess of potassium compounds passing over soil containing ammonium compounds, and therefore ammonium compounds should be eliminated; and we do find that, speaking generally, the larger quantities of potash are accompanied by an increase of ammonia; but against this there appears the "blank" plot, with *maximum* potash and *minimum* ammonia, but I and II are not an exception; likewise in 1880 from the "blank" there passed 1.35 grams NH_4 and 4.5 grams K_2O , while from the "clover" 0.031 gram NH_4 and 1.2 grams K_2O .

Percolation.—The quantity of water which passed through the experimental soils was, as has been stated (Table I), very varying, and

as the depth of the soil was much less than the shallowest employed by Messrs. Lawes and Gilbert (20 inches) no satisfactory comparisons can be drawn between the two sets of experiments. Messrs. Lawes and Gilbert found, during the months June to September, that the percolation was 19·7 of the rainfall (*Inst. Civ. Eng.*, 14); during the same period my uncropped soil gave percolation 21·2 per cent. of rainfall.

	I.	II.	3.	4.	5.	6.	7.	8.
Percentage of } percolation } to rainfall }	26·5	32·1	15·3	21·1	14·1	12·9	26·8	21·2

This figure, 21·2, is below that given by Mr. Greaves (28 per cent.) and above that given by M. Gasparin (20 per cent.);* but seeing that the soils were all of various depths and kinds, that 28 per cent. and 20 per cent. are derived from the observations extending over twelve months, and not over only four, no satisfactory conclusion can be arrived at. Marié-Davy appears to have ascertained the percolation through soils when covered with different kinds of vegetation, but I have not as yet been able to compare his results with mine, and I have therefore introduced the above table of percolation for future comparison.

I would, however, call attention to the “turnips” and “beans,” where we find with the same rainfall of 16·88 inches (15·529 gallons) that there is a very marked difference between the percolation through one soil and through the other, viz., 26·8 per cent. and 14·1 per cent. of the rainfall; in both cases there were only half-a-dozen plants growing, and both presenting apparently a considerable leaf-surface; and whereas that of the turnips afforded considerable shelter to the soil beneath, that of the beans afforded but little, as these latter plants grew high and strong. Now percolation is dependent on evaporation, and an increase of vegetation causes diminution of percolation. The large amount of dry matter in the beans (138 grams) is the result of vigorous growth, which has diminished the passage of water through the soil to a much greater extent than in the case of the turnips, whose dry matter amounted only to 20 grains. Clover (No. 6), with a smaller amount of dry matter (22·01 grams), seems to have allowed less percolation than any other plant (viz., 12·9 per cent. rainfall); but I think that this must be due to the fact that, as the crop was very thick and strong, the whole of the rain did not reach the soil, but remained in the leaves and evaporated.

Little need be said concerning plots I and II, as the depth of the soil was manifestly insufficient to allow of any conclusions, however

* The figures quoted from MM. Greaves and A. Gasparin are for 12 months, and not for June to September only.

indefinite, being drawn from the amount of water percolating through; in fact I introduced these two merely to supplement last year's experiments, and have found that they, on the whole, corroborate the results then obtained, however incorrect they may be.

Differing vastly as the plants do in their effects on the soil, the figures in Table II representing the percentage composition of the solid matter removed by drainage, show that the mean of all these influences, as measured by the composition of the residues, is very similar to those produced by the slow action of air and rain alone. Still, seeing that the absolute amount of soluble matter removed and lost when no plants are growing, is so much greater than during the growth of a crop, it evidently is far better to allow some crop to remain on the land than to leave it lying absolutely fallow. The experiments also show why a deep soil is more fitted for growth than a shallow soil, more especially in regard to the nitric acid. I hope at some future time to repeat these experiments in a more extended form, and in pans of a different shape, which shall prevent all chances of the water passing down between the sides and the soil, and trust, after a sufficient number of seasons, to arrive at some definite results. In conclusion, I must return my hearty thanks to my assistant, Mr. C. Rawson, F.C.S., for the care with which he has performed the various analyses connected with this work.