ON

RAINFALL;

EVAPORATION AND PERCOLATION.

BY

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EVAPORATION AND PERCOLATION.[1]

Dr. GILBERT remarked that Mr. Lawes and himself had been for some time engaged in percolation experiments as well as in rain-gauge determinations. He had accordingly arranged a few facts connected with those experiments extending over a period of five years. He could not give the results of so many years as Mr. Greaves, nor were theirs obtained under exactly parallel conditions. They were undertaken with a different view, their object being an agricultural one, in relation to vegetation, and the characters of soils. Mr. Greaves's percolation gauge was filled with soil artificially; they, on the other hand, took the soil just as it was; they dug down and undermined it, putting iron plates which were drilled with holes underneath; they gradually got it underpinned in that way, and built it in with brick and cement, so that they had an isolated square of soil entirely undisturbed. The area of each gauge was one-thousandth of an acre. They had one such gauge with 20 inches, one with 40 inches, and one with 60 inches depth of soil; so that they were able to answer some of the questions with regard to capillary action to which reference had been made. Of previous determinations, Dr. Dalton's had indicated that 25 per cent. of the rain percolated; those of Mr. Dickinson showed up to a certain date 42·5 per cent.; those of M. Maurice, at Geneva, 39 per cent.; those of

[1] These remarks were made, at the Institution of Civil Engineers, on the 29th of February, 1876, in the course of the discussion upon the Papers by Mr. Symons "On Floods in England and Wales in 1875," and by Mr. Greaves "On Rainfall and on Percolation."

M. Gasparin, in the South of France, 20 per cent.; those of M. Risler, near Geneva, 30 per cent.: or an average of 31·3 per cent. under different conditions in five different localities. Mr. Greaves gave 28 per cent. For a period of five years Mr. Lawes and himself found 36·8 per cent. of the rainfall percolating through 20 inches, 36 per cent. through 40 inches, and 28·6 per cent. through 60 inches. They had a natural soil, a subsoil with its natural consolidation; whereas Mr. Greaves's was an artificial soil, a much more open soil than the materials of which it was composed would form in their natural condition. (See Table I., *post*, p. 7.) The particulars of experiments on percolation by Ebermayer, in Bavaria, were given in Tables II. and III., *post*, pp. 8 and 9. To show how difficult it was to imitate soil in its natural condition, he might mention that, wishing to extend their experiments, they attempted to fill, by calculation, a number of tubes, 5 feet deep and 2 feet in diameter, with the soil of the immediately adjoining field in its exact natural condition. After putting in 3 feet of soil, pouring a great deal of water through, and applying a weight of more than 1 ton for many months, the soil had not sunk down to the 3 feet by about 6 inches. It was almost impossible by artificial means to get a soil like the natural one. Another difference in the mode of estimation was that they took the harvest year, from the 1st of September to the end of August. The rainfall in the first year was 27½ inches; in the succeeding years 29 inches, 30½ inches, 21¾ inches, and 30¾ inches, or an average of nearly 28 inches. Of those 28 inches about 10¼ inches percolated through 20 inches, 10 inches through 40 inches, and only 8 inches through 60 inches of soil; so that it was clear that capillary action had had its effect far below the depth Mr. Greaves supposed. In fact it was obvious that it had been operative below 40 inches, as was illustrated in the more detailed figures. Beginning in September, that was after warm and comparatively dry weather, there was less water going through 40 inches than through 20 inches, and less through 60 inches than through 40 inches depth of soil; and so it went on until the winter rains accumulated, when the reverse happened, and there was sometimes more through the 60 inches than through the 20 inches. (See Tables IV. and V., *post*, pp. 10 and 11.) Capillary action therefore certainly had its influence on percolation, or rather on evaporation—the complement to it—far below the depth that had been mentioned. Mr. Greaves's observations indicated an average of about 7 inches of percolation. This determination rested upon experiments made on soil covered with vegetation, and of course the surface of the country was mostly

so covered; but the amount of vegetation much determined the amount of percolation. (See Tables VI. and VII., *post*, p. 12.)

Ebermayer quoted Professor Woldrich as having determined the amount of percolation (2 feet deep) through turf, and through bare ground, at Salzburg and in the neighbourhood of Vienna. At Salzburg the percolation was –

In May 25·2 per cent. less through turf.
„ June 53·1 „ „
„ July 23·4 „ „
„ Aug. 29·2 „ „
„ Sept. 12·7 „ „

The difference was the least in January. In May, both at Salzburg and at Vienna, more than twice as much percolated through bare earth as through turf. From June 16–30 there percolated at Salzburg—

2·12 inches (Eng.) through bare earth.
0·02 „ „ „ turf.

The maximum difference was in June and July, and less in autumn and winter. Ebermayer concluded that in the summer half-year forest soil was the moistest; bare, open ground less moist; turf the driest.

From the results of an extended series of experiments on the amount of water given off by plants during their growth, it might be roughly estimated that, for every ton of really dry substance grown, a depth of 3 inches of rain would be evaporated through the vegetation. For every ton of hay, in its natural condition, about 2½ inches of rain would pass through the plant. It was obvious that, where there was vegetation, percolation would be diminished, and especially where the growth extended through nearly the whole of the year, as in the case of grass land. The water would not be safe until it reached a lower depth than if the land were not covered, as in the case of the percolation experiments to which he had referred. (See also Tables VI. and VII., *post*, p. 12.) He thought that the larger amounts of percolation obtained in their own experiments than in those of Mr. Greaves were the resultant of two opposite agencies: they had no vegetation to pump the water out, but, on the other hand, Mr. Greaves's soil had no doubt been more pervious than theirs.

M. Marié-Davy, Director of the Meteorological Observatory, at Montsouris, Paris, had also made numerous experiments on the amount of water evaporated by different plants during growth,

and also on the amount evaporated from soils of different kinds, or covered with different descriptions of vegetation; but the results were too numerous and varied to be conveniently summarised in a tabular form.

With reference to some observations by Mr. Symons, he might be permitted to refer to the effects of manures in fouling water. When that gentleman visited them some time ago, he pointed out two plots of wheat, one of which had been manured in the autumn, and the other in the spring. There had been a wet winter, and under those conditions the crop manured in the spring was much better than that manured in the autumn. In dry winters it was just the contrary. At such times the crop manured in the autumn picked up more of the active manures, and less got into the drains, so that there was a better root-distribution, and eventually a better crop. Those experiments on the growth of wheat had been carried on for more than thirty years. The drain of each plot was opened, and the drainage-water occasionally collected for analysis. Dr. Voelcker and Dr. Frankland had analysed many of those waters. The results showed, on an average, that where no nitrogenous manure had been used for many years, the amount of nitrogen (as nitrates, &c.) in the drainage-water was 0·43 part per 100,000; when 41 lbs. of nitrogen per acre per annum were put on in the form of ammonia salts, the amount was 0·82 part; with 82 lbs., 1·44 part; with 123 lbs., 1·81 part; almost progressing in the ratio of the amount of nitrogen put upon the soil. Two analyses by Dr. Voelcker and four by Dr. Frankland gave 1·26 part of nitrogen per 100,000 parts of drainage-water from land manured every year with farmyard manure. (See Table VIII., *post*, p. 13.) Some of the plots were manured far more heavily than was usual in agriculture, so that there need be no fear of anything like the fouling of water referred to from ordinary agricultural operations. Of course it would be more in light soils than in heavy lands. The results described had been obtained in somewhat heavy soil. The importance of watching the matter was very great. He did not, however, think that when the matters had passed through a considerable depth of soil there was so much danger from ordinary agriculture as was sometimes supposed, although it was true the drainage-water might not indicate a very good previous history.

The following tables embodied summaries of the results to which he had referred (see pp. 7–13).

TABLE I.—PERCOLATION and EVAPORATION; SUMMARY of the RESULTS of VARIOUS OBSERVERS.

Authority.	Conditions of the Experiments, &c.	Duration and Dates.	Percolation.	Evaporation.
		Years.	Per cent.	Per cent.
Dr. Dalton . .	("Mem. Lit. Phil. Soc. of Manchester," vol. v., part 2.) Cylinder 10 inches diameter, 3 feet deep, open at top, closed at bottom; filled with earth and sunk into the ground level with the surface; one side left exposed for access to bottles—after first year surface of soil covered with grass	3 1796–1798	25·0	75·0
Mr. Dickinson .	("Jour. Royal Agric. Soc.," vol. v.). Cylinder 12 inches diameter, 3 feet deep; perforated bottom with receptacle for collection of drainage water; grass was grown on the surface of the soil (a sandy gravelly loam) in the cylinder; evaporation included that due to vegetable growth. Average rainfall during 8 years = 26·61 inches	8 1836–1843	42·5	57·5
M. Maurice . .	Geneva ("Bibl. Universelle de Genève, Sciences et Arts," t. 1). Cylindrical iron vessel with earth, rainfall averaged over two years about 26 inches per annum	2 1796 and 1797	39·0	61·0
M. Gasparin . .	Orange, South of France ("Cours d'Agriculture," t. ii., p. 116). Experiments somewhat similar to those of M. Maurice. Average rainfall 28 inches per annum	2 1821 and 1822	20·0	80 0
M. Risler . . .	Calèves, near Nyon, Switzerland ("Archives des Sciences de la Bibliothèque Universelle," Sept. 1869). By gauging drains 1·2 mètre (about 4 feet) deep; compact and impervious subsoil; land cropped, as usual, during experiment; average rain 41 inches per annum; evaporation includes that due to vegetable growth . .	2 1867 and 1868	30·0	70·0
		Mean . . .	31·3	68·7
Mr. Greaves . .	Lee Bridge. Gauge, slate box; area 1 square yard, 1 yard deep; soil, soft earth with loam, gravel and sand mixed, trodden in, and turfed; average rainfall 25·8 inches	22 1852–1873	26·6	73·4
	Similar gauge; with sand; average rainfall 25·7 inches	14 1860–1873	83·2	16·8
	Estimated average for Home Counties; rainfall 25 inches . . .	.. ..	28·0	72·0
Lawes and Gilbert	Rothamsted, Herts. Gauge one-thousandth of an acre area; soil, rather heavy loam with clay subsoil, built in, in natural state of consolidation, with brick and cement. (Chalk below.) Average rainfall 28 inches — 20 ins. deep	5 Sept. 1870—Aug. 1875	36·8	63·2
	Do. do. do. 40 „ „	5 Sept. 1870—Aug. 1875	36·0	64·0
	Do. do. do. 60 „ „	5 Sept. 1870—Aug. 1875	28·6	71·4

TABLE II.—EXPERIMENTS on PERCOLATION, by EBERMAYER, in BAVARIA.

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for some time to acquire normal physical characters.

—	Percolation through Soil. Inches (English).			
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]	Average Rainfall.
12 Months, March 1868—*Feb.* 1869; *Mean of* 4 *Stations.*				
Open ground, bare	20·01	18·08	19·41	36·0
Forest, without litter	18·56	..	..	27·5
„ with litter	20·63	21·48	16·54	
Spring. March, April, May 1868.				
Open ground, bare	5·22	5·35	5·86	
Forest, without litter	4·99	..	..	
„ with litter	5·69	5·75	6·00	
„ with litter + or − open ground	+0·47	+0·40	+0·14	
Summer. June, July, August 1868.				
Open ground, bare	2·26	1·62	1·09	
Forest, without litter	4·12	..	..	
„ with litter	5·77	5·42	3·00	
„ with litter + or − open ground	+3·51	+3·80	+1·91	
Autumn. Sept., Oct., Nov. 1868.				
Open ground, bare	4·41	4·08	4·09	
Forest, without litter	3·96	..	..	
„ with litter	3·84	4·52	3·48	
„ with litter + or − open ground	−0·57	+0·44	−0·61	
Winter. Dec., Jan., Feb. 1868–9.				
Open ground, bare	8·13	7·06	8·36	
Forest, without litter	5·49	..	..	
„ with litter	5·34	5·78	4·07	
„ with litter + or − open ground	−2·79	−1·28	−4·29	
Growing Period. April—September, inclusive, 1868.				
Open ground, bare	5·40	4·90	4·69	
Forest, without litter	7·62	..	..	
„ with litter	9·69	9·84	7·13	
„ with litter + or − open ground	+4·29	+4·29	+2·44	

[1] French feet.

TABLE III.—EXPERIMENTS ON PERCOLATION, by EBERMAYER, in BAVARIA.

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for some time to acquire normal physical characters.

Percentage of Percolation to Rainfall.

	Percolation through Soil. Per cent. of Rainfall.		
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]
12 *Months, March* 1868—*Feb.* 1869 ; *Mean of* 4 *Stations.*			
Open ground, bare	54	50	53
Forest, without litter	67	..	..
„ with litter	74	77	60
Spring. March, April, May 1868.			
Open ground, bare	55	56	64
Forest, without litter	70	..	..
„ with litter	81	81	83
Summer. June, July, August 1868.			
Open ground, bare	19	14	11
Forest, without litter	52	..	..
„ with litter	72	65	36
Autumn. Sept., Oct., Nov. 1868.			
Open ground, bare	54	51	49
Forest, without litter	60	..	..
„ with litter	60	68	54
Winter. Dec., Jan., Feb. 1868–9.			
Open ground, bare	94	89	99
Forest, without litter	91	..	..
„ with litter	94	97	63
Comparison of Winter and Summer Half-years.			
Open ground, bare { Oct.—March	72	67	76
Open ground, bare { April—Nov.	23	24	24
Summer less than winter	49	43	52
Forest, without litter { Oct.—March	80	..	..
Forest, without litter { April—Nov.	57	..	..
Summer less than winter	23	..	..
Forest, with litter { Oct.—March	86	87	73
Forest, with litter { April—Nov.	75	76	62
Summer less than winter	11	11	11
July only.			
Open ground, bare	11	6	7
Forest, with litter	58	61	34

[1] French feet.

TABLE IV.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Sept. 1870—Aug. 1871	27·55	9·64	9·42	5·81	17·91	18·13	21·74
„ 1871 „ 1872	29·02	9·69	9·40	8·24	19·33	19·62	20·78
„ 1872 „ 1873	30·66	14·35	13·67	12·03	16·31	16 99	18·63
„ 1873 „ 1874	21·69	5·47	5·11	3·61	16·22	16·58	18·08
„ 1874 „ 1875	30·74	12·25	12·72	10·30	18·49	18·02	20·44
Average per annum .	27·93	10·28	10·06	8·00	17·65	17·87	19·93
September	2·88	0·68	0·43	0·30	2·20	2·45	2·58
October	3·19	1·37	1·09	0·76	1·82	2·10	2·43
November	2·08	1·41	1·30	1·01	0·67	0·78	1·07
December	2·15	1·52	1·51	1·14	0·63	0·64	1·01
January	3·11	2·15	2·43	2·08	0·96	0·68	1·03
February	1·47	0·69	0·75	0·59	0·78	0·72	0·88
March	1·43	0·53	0·57	0·47	0·90	0·86	0·96
April	1·76	0·26	0·28	0·22	1·50	1·48	1·54
May	1·91	0·21	0·23	0·19	1·70	1·68	1·72
June	2·77	0·48	0·43	0·36	2·29	2·34	2·41
July	3·47	0·97	1·03	0·87	2·50	2·44	2·60
August	1·71	0·01	0·01	0·01	1·70	1·70	1·70
Total	27·93	10·28	10·06	8·00	17·65	17·87	19·93
Average per month .	2·33	0·86	0·84	0·67	1·47	1·49	1·66

TABLE V.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percentage of Percolation to Rainfall.					
		Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.						
Sept. 1870 — Aug. 1871	27·55	34·9	34·2	21·1	65·1	65·8	78·9
„ 1871 „ 1872	29·02	33·4	32·4	28·4	66·6	67·6	71·6
„ 1872 „ 1873	30·66	46·8	44·6	39·2	53·2	55·4	60·8
„ 1873 „ 1874	21·69	25·2	23·5	16·6	74·8	76·5	83·4
„ 1874 „ 1875	30·74	39·9	41·4	33·5	60·1	58·6	66·5
Average . .	27·93	36·8	36·0	28·6	63·2	64·0	71·4
September	2·88	23·6	14·9	10·4	76·4	85·1	89·6
October	3·19	42·9	34·2	23·8	57·1	65·8	76·2
November	2·08	67·8	62·5	48·6	32·2	37·5	51·4
December	2·15	70·7	70·2	53·0	29·3	29·8	47·0
January	3·11	69·1	78·1	66·9	30·9	21·9	33·1
February	1·47	47·0	51·0	40·2	53·0	49·0	59·8
March	1·43	37·0	39·9	32·9	63·0	60·1	67·1
April.	1·76	14·8	16·0	12·5	85·2	84·0	87·5
May	1·91	11·0	12·0	9·9	89·0	88·0	90·1
June	2·77	17·3	15·5	13·0	82·7	84·5	87·0
July	3·47	28·0	29·7	25·1	72·0	70·3	74·9
August	1·71	0·6	0·6	0·6	99·4	99·4	99·4
Total.	27·93						
Average	2·33	36·8	36·0	28·6	63·2	64·0	71·4

TABLE VI.—EXPERIMENTS at ROTHAMSTED, HERTS, ILLUSTRATING the INFLUENCE of VEGETATION on EVAPORATION. RESULTS RELATING to PERMANENT GRASS LAND.

	Plot 3. Without Manure.	Plot 9. Mineral Manure and Ammonia-salts.	Plot 14. Mineral Manure and Nitrate of Soda.
	Cwt.	Cwt.	Cwt.
Produce of Hay per acre.			
Average 15 (or 13) years, 1856-1870	22¾	52⅜	57⅛
Year of drought, 1870	5¾	29½	56¼
Deficiency in 1870	17	22¼	1⅛
Manured more than unmanured in 1870	..	23¾	50½
Moisture in the Soils (dried at 100° C.) at different depths.	Per cent.	Per cent.	Per cent.
Samples collected, July 25-6, 1870. First 9 inches	10·83	13·00	12·16
Second „ „	13·34	10·18	11·80
Third „ „	19·23	16·46	15·65
Fourth „ „	22·71	18·96	16·30
Fifth „ „	24·28	20·54	17·18
Sixth „ „	25·07	21·34	18·06
Mean	19·24	16·75	15·19
Estimated quantities of Water per acre.[1]	Tons.	Tons.	Tons.
Total to the depth of 54 inches	1,546	1,346	1,221
Manured less than unmanured land	..	200	325

TABLE VII.—DITTO DITTO. RESULTS RELATING to the GROWTH of BARLEY.

	Barley Land.	Adjoining Fallow Land.[2]	Fallow Land more than Barley Land.
	Per cent.	Per cent.	Per cent.
Moisture in the Soils (dried at 100° C.) at different depths.			
Samples collected June 27-8, 1870. First 9 inches	11·91	20·36	8·45
Second „ „	19·32	29·53	10·21
Third „ „	22·83	34·84	12·01
Fourth „ „	25·09	34·32	9·23
Fifth „ „	26·98	31·31	4·33
Sixth „ „	26·38	33·55	7·17
Mean	22·09	30 65	8·56[2]
Estimated quantities of Water per acre.[1]	Tons.	Tons.	Tons.
To the depth of 54 inches	1,863	2,772	909[2]

[1] The estimates given above of the "quantities of Water per acre" must of course be taken as approximate and illustrative only.

[2] About 0·65 inch of rain had fallen ten days previous to the collection of the soils, and 0·10 inch three days before; and for several days since the heavier rainfall some soil had been thrown on the uncropped land, probably retarding evaporation. Hence doubtless part of the excess in the uncropped land.

TABLE VIII.—COMPOSITION of DRAINAGE WATER from PLOTS DIFFERENTLY MANURED; BROADBALK FIELD, ROTHAMSTED. WHEAT EVERY YEAR, COMMENCING 1844. NITROGEN as NITRATES and NITRITES, per 100,000 parts of WATER.

Dr. Voelcker's and Professor Frankland's Results.

Samples collected at different periods of the year in 1866, 1867, 1868, 1872, *and* 1873.

Plots.	——	Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water.					
		Dr. Voelcker's Results.		Dr. Frankland's Results.		Mean.	
		Experiments.		Experiments.		Experiments.	
2	14 tons farmyard manure, every year	2	1·606	4	0·922	6	1·264
3–4	Without manure, every year	5	0·390	6	0·316	11	0·353
5	Mineral manure alone	5	0·506	6	0·349	11	0·428
6	" " and ammonia-salts (41 lbs. nitrogen)	5	0·853	6	0·793	11	0·823
7	Mineral manure and ammonia-salts (82 lbs. nitrogen)	5	1·400	6	1·477	11	1·439
8	Mineral manure and ammonia-salts (123 lbs. nitrogen)	5	1·679	6	1·951	11	1·815
9	Mineral manure and nitrate soda (82 lbs. nitrogen)	5	1·835	5	1·039	10	1·437

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