THE NATURE AND AMOUNT OF THE FLUCTUATIONS IN NITRATE CONTENTS OF ARABLE SOILS.

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THE study of the fluctuations in the amounts of nitrate present in arable soils is important both from the practical and the scientific points of view. The nitrate supply in the soil is very commonly a limiting factor in crop production in Great Britain, so that any process which increases the nitrate supply tends to increase productiveness, and vice versa. From the scientific point of view the interest is even wider. No soil constituent, not even the moisture, shows such great fluctuations as the nitrates, and none is so susceptible to external influences. Further, the nitrate represents the end point in one chain of decompositions and the amount formed over a given period is therefore a measure of the extent to which this particular decomposition has proceeded.

The experiments of Warington, Omelianski[1] and others have proved, as clearly as any negative proposition can be proved, that nitrates are formed only from nitrites and these only from ammonia. The formation of nitrate has been shown in an earlier paper[2] to be the quickest of these stages while the formation of ammonia is the slowest. The proof is that under no natural conditions have we ever found any accumulation of ammonia in the soil. At Rothamsted the amount found is a constant minimum, about 1 or 2 parts per million of soil. Such a negative proof is obviously not rigid, but so far as all the evidence goes this non-accumulation of ammonia is characteristic of soils kept under natural conditions of temperature, moisture and aeration.

[1] *Centr. Bakt. Par.*, Abt. II. 1899, **5**, 473—493: "Ueber die Nitrification des organischen Stickstoffes."

[2] This *Journal*, 1909, **3**, 233.

The amounts of nitrate in the soil at different periods of the year.

Systematic determinations of the nitrate in the soil of arable land at different times of the year bring out the very remarkable fact that the amount of nitrate is commonly at a maximum, not in late summer as is often stated, but in late spring, or early summer. This is shown in Table I where the means of all the results on uncropped land[1] are collected, and in Table II where the results of cropped land are given. The highest amount, or nearly the highest, occurs in May or June, after which there is sometimes a slight increase but sooner or later a fall. What is even more remarkable is the rapid rate of accumulation of nitrate in the spring; the rise from the winter minimum to the early summer maximum is very rapid, and usually much quicker than anything obtained later.

After the mild wet winters of 1911—12 and 1912—13 this rapid accumulation of nitrate did not set in directly the warm weather began; there was a well marked lag. Thus in 1912 there was no increase in the stock of soil nitrate during the month of May but a very marked increase during June. Yet the weather appeared to be very favourable in May as shown by the following data:

	Period of no accumulation of nitrates, April 28—May 25				Period of marked accumulation of nitrates, May 26—June 22			
	1st week, Ap. 28—May 4	2nd week, May 5—11	3rd week, May 12—18	4th week, May 19—25	1st week, May 26—June 1	2nd week, June 2—8	3rd week, June 9—15	4th week, June 16—22
Rainfall, inches	0·40	0 03	0·22	0·32	0·43	1·20	1·02	0·12
Mean temp., °F.	49·0	58·9	54·8	52·2	53·4	54·0	56·1	60·0
"Accumulated heat" (day degrees above 42° F.)	61	118	90	71	81	84	99	126
	April 30	May 13		May 22				June 26
Moisture in soil, per cent. (Plot 7[2])	17·5	14·8		15·5				19·3
Nitrate in soil, parts per million (Plot 7[2])[2]	15	18		12				28

[1] Fruit trees were growing on the loams and the clay but the land was kept cultivated and free from any quick growing crop.

[2] Similar data for other plots will be found in Table II. Pouget and Guiraud (*Compt. Rend.* 1909, **148**, 725), working at the School of Agriculture, Maison-Carrée, Algeria, found

Again in 1913 no accumulation of nitrates took place during May in spite of the favourable weather, but a rapid rise set in during the first week in June:—

	Period of no accumulation of nitrates, May 11—31			Period of marked accumulation of nitrates, June 1—July 5				
	May 11—17	May 18—24	May 25—31	June 1—7	June 8—14	June 15—21	June 22—28	June 29—July 5
Rainfall, inches	0·07	0·06	0·31	0·35	0·31	0·34	0·06	0·28
Mean temp., °F.	51·3	52·2	61·5	55·2	55·1	59·2	57·0	58·4
Accumulated heat (day degrees above 42° F.)	69	71	137	92	92	120	105	115
		May 19	May 31		June 9		June 23	July 9
Moisture in soil, per cent. (Agdell, Plot 2)		16·3	14·5		16·0		12·2	13·3
Nitrates in soil, parts per million:—								
Agdell, Plot 2		7	4		11		3	18
,, Plot 1		8	5		15		4	14
Hoos 1·0		5	5		18		4	21

None of these plots received any manure during the season.

In both cases the preceding winter had been mild and wet so that the soil had lain wet for many weeks. In 1909, after a drier and colder winter, the rise set in at an earlier date and was already manifest on some plots early in April, although the weather appeared to be distinctly unfavourable (see Table on opposite page).

The subsequent changes in the amount of nitrate differ accordingly as the land is cropped or not. Where there is no crop the nitrates accumulate to a greater extent than where a crop is growing; but as

that nitrates almost entirely disappeared from the soil in the wet months, Jan.—April, but did not at once begin to accumulate when drier, warmer weather set in. Only little nitrate was found during May, although the mean temperature for the month was 18·3° C.; not till June was the accumulation at all marked. The results obtained were:

	Feb. 12	Feb. 27	April	May 22	June 6	June 13	June 20
N. as nitrate, parts per million	2	1·5	trace	3·7	6·3	7·6	7·3
Mean temperature for the month, °C.		8·8	11·9	18·2	18·5		
Rainfall for the month, mm.		93	76·5	10·8	9·7		

the crop introduces a new factor we shall begin by discussing the case of land either wholly fallow or else only carrying young fruit trees, where the complication due to the crop is reduced to a minimum.

	1st Period, March 7—April 10					2nd Period, April 11—May 8			
	March 7—13	March 14—20	March 21—27	Mar. 28—Apr. 3	April 4—10	April 11—17	April 18—24	Apr. 25—May 1	May 2—8
Rainfall, inches	0·29	0·53	0·65	0·99	0	0·20	0·64	0·83	0
Mean temp., °F.	35·8	37·1	43·5	43·4	44·8	48·4	49·0	46·9	48·4
Accumulated heat (day degrees above 42° F.	-43	5	26	29	68	60	54	47	60
	April 6					May 7			
	Broadbalk Orchard		Hoos dunged Plot 7²			Broadbalk Orchard		Hoos dunged Plot 7²	
Moisture in soil, %...	15·5		20·0			13·7		18·0	
Nitrate in soil, parts per million	4		22			8		21	

1. *Land wholly or mainly left fallow. Effect of soil.* Reference to Table I shows that under similar treatment the sand is at all times except winter poorer in nitrates than loams or clays. The highest amount was recorded in May 1909 when 8 parts per million were found in the top 9 inches, or 36 lbs. per acre in the top 18 inches, but more usually only about half these quantities are present, and during the hot dry summer of 1911 the amounts fell to 2·5 parts per million, or 13 lbs. per acre in the top 18 inches.

In winter and early spring the loam contained approximately the same amount of nitrate as the sand, but later on—from May onwards—it contained much more. The maximum amount found at Ridgmont was 19 parts per million in the top 9 inches, or 95 lbs. per acre in the top 18 inches: at Rothamsted still higher quantities (23 parts per million or 115 lbs. per acre) occurred in the hot dry summer of 1911.

The clay contained more nitrate in winter and early spring than the loam but less in summer and autumn. The amount never fell below 4 parts per million, or 20 lbs. per acre in the top 18 inches, nor, on the other hand, did it rise above 14 parts per million, or 60 lbs. per acre; there were no sharp falls and no sharp rises.

Comparing the results for the three types of soil it is evident that the loams are most suitable for the accumulation of nitrate, next comes the clay, while the sand is the least suitable. The sand and the loam lose their nitrates equally completely in the winter, the amounts running down to 9 lbs. per acre, or 1 part per million. The clay suffers much less loss, the lowest amount found being 20 lbs. per acre or 4 parts per million. Thus the total fluctuation is least in the clays and most in the loams. These relationships are shown in the curves for 1912 in Fig. 1. It will be shown later (p. 49) that organic matter conditions the retention of nitrates during winter just as clay does, the

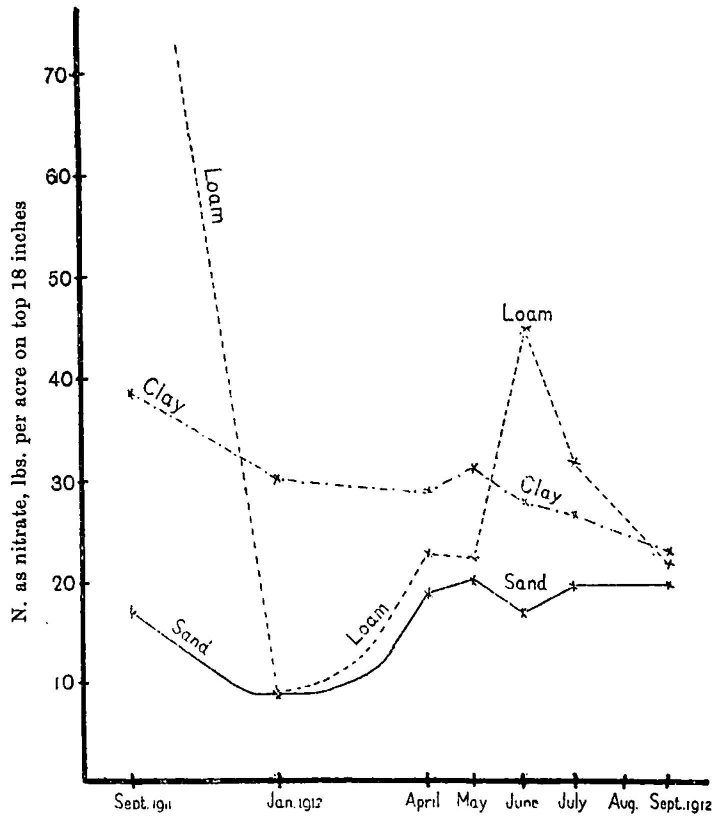

FIG. 1. Effect of soil type on accumulation of nitrates.

dunged plots at Rothamsted always containing more nitrate in winter than those receiving artificial fertilisers only.

It will be observed that the amounts of nitrogen as nitrate do not usually exceed certain limits, which in these experiments were :—

	Parts per million	lbs. per acre 0—18″
Sand	6	28
Loam	23	115
Clay	14	60

The heavily dunged loams, however, sometimes contained as much as 37 parts per million.

This limit to the accumulation of nitrate in soil has already been noticed in an earlier paper[1].

Effect of Season. Unfortunately it is not possible to characterise climatic factors with sufficient exactness for precise discussion, but some interesting results are obtained from a general comparison of the different seasons. The summer and autumn of 1909 and 1912 were cold and wet; those of 1911 were hot and dry. Table I shows that the amounts of nitrate present in 1911 are distinctly higher than in 1909 and 1912. In the latter years there was no tendency for nitrates to accumulate in autumn; in 1911, on the other hand, there was a well marked tendency in this direction, especially on two of the loams. Indeed at Rothamsted the nitrates attain in September 1911 the extraordinary high level of 115 lbs. per acre or 22 parts per million. Thus a hot dry summer favours the accumulation of nitrates on loams in autumn, a cold wet summer does not. These relationships are shown in Fig. 2. In the dry but cool summer of 1913 the maximum was attained in June (on one or two plots in July) and practically no change set in till the winter leaching began.

The rule does not hold universally on sandy soils. Of the four sand plots studied three showed no gain in nitrate during or after the hot weather, and only the fourth (No. 21) behaved like the loams and clays:—

N. as nitrate, lbs. per acre, 0—18 ins. in 1911.

No.	May 22	June 15	July 13	Aug. 9	Sept. 7
23	26	13	12·5	15	17
25	21	18	15	14·5	14
27	24·5	16	10	16	10
21	23	12	12	29	27

The soils, however, were very dry, the moisture steadily falling from 5 to 1·3 per cent. On the clay soil at Ridgmont no rise of nitrates was observed in autumn.

[1] This *Journal*, 1913, **5**, 197.

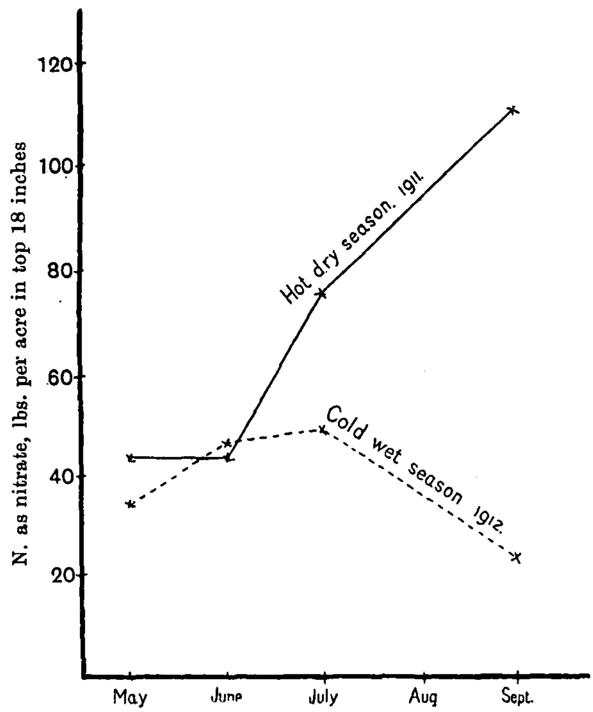

FIG. 2. Effect of season on accumulation of nitrates on the loam at Rothamsted.

TABLE I. *N. as nitrate, parts per million of dry soil. Soil uncropped except for fruit trees.*

A. Sand, Milbrook (no manure applied during the whole period)

1909	March	May	July	Sept.		
0—9″	5	8	3	2		
9—18″	4	5	3	2		
1910	June	Aug.	Sept.			
0—9″	6	4	5			
9—18″	5	3·5	3			
1911	May	June	July	Aug.	Sept.	
0—9″	5	3	2·5	4	4	
9—18″	4	3	2	3	2	
1912	Jan.	April	May	June	July	Sept.
0—9″	2	5	4	3	3	4
9—18″	1	2	3	3	4	3

C. Clay, Ridgmont (artificial manures applied in March or April containing 16 lbs. N. as $NaNO_3$, i.e. 7 parts per million)

1909	March	May	July	Sept.		
0—9″	8	7	4	5		
9—18″	12	5	4	4		
1910	June	Aug.	Sept.			
0—9″	7	5	9			
9—18″	7	5	5			
1911	May	June	July	Aug.	Sept.	
0—9″	11	14	10	6	11	
9—18″	9	11	6	5	5	
1912	Jan.	April	May	June	July	Sept.
0—9″	6	5	6	8	6	6
9—18″	6	7	7	4	5	4

TABLE I (*cont.*).

Loams I and II, Ridgmont (artificial manures applied in March or April containing 16 lbs. N. as $NaNO_3$, i.e. 7 parts per million)						
1909	March	May	July	Sept.		
Loam I						
0—9″	5	15	2	3·5		
9—18″	4	7	1·5	2		
Loam II						
0—9″			4	5		
9—18″			5	3		
1910	June	Aug.	Sept.			
Loam I						
0—9″	3	3	1			
9—18″	2	2	3			
Loam II						
0—9″	7	12	12			
9—18″	4	6	7			
1911	May	June	July	Aug.	Sept.	
Loam I						
0—9″	11	11	8	6	6	
9—18″	6	5	6	3	4	
Loam II						
0—9″	16	19	15	15	18	
9—18″	9	12	8	8	11	
1912	Jan.	April	May	June	July	Sept.
Loam I						
0—9″	1	3	5	6	4	3·5
9—18″	1·5	3	3	6	2	2
Loam II						
0—9″	1	4	4	10	6	3
9—18″	1·5	3	3	4	4	4

Rothamsted (no manure applied)						
1909	April	May	July	Oct.		
0—9″	5	12	6	5		
9—18″	4	6	6	7		
1910	May	July	Sept.			
0—9″	13	16	8			
9—18″		6	8			
1911	May	June	July	Sept.		
0—9″	10	8·5	17	23		
9—18″	7	8	12	22		
1912	Feb.	April	May	June	July	Sept.
0—9″	7	4	7	9	11	5
9—18″	5·5	3	6	8·5	7	4

NOTE.—During the experimental period the following nitrogenous manures were applied:—

Sand—none.

Clay and Loam (Ridgmont) 97 lbs. $NaNO_3$ (containing 16 lbs. N.) per acre on
March 20, 1909 (i.e. 7 days *after* the samples were taken),
March 11, 1910,
April 12, 1911,
April 24, 1912 (i.e. 9 days *before* the May samples were taken).

TABLE I (*cont.*). *N. as nitrate, lbs. per acre in dry soil,* 0—18 *ins.*

	A. Sand, Milbrook (no manure applied during the whole period)						C. Clay, Ridgmont (artificial manures containing 16 lbs. N. as $NaNO_3$ applied in March or April)					
1909	March	May	July	Sept.			March	May	July	Sept.		
	25	36	17	11			47	30	20	22		
1910	June	Aug.	Sept.				June	Aug.	Sept.			
	28	20·5	23				35	24	33			
1911	May	June	July	Aug.	Sept.		May	June	July	Aug.	Sept.	
	25	15	13	18	17		47	60	38	26	39	
1912	Jan.	April	May	June	July	Sept.	Jan.	April	May	June	July	Sept.
	9	19	20	17	20	20	30	29	31	28	27	23

	Loams I and II, Ridgmont (artificial manures containing 16 lbs. N. as $NaNO_3$ applied in March or April)						Rothamsted (no manure applied)					
1909	March	May	July	Sept.			April	May	July	Oct.		
Loam I	28	69	11	17			21	46	31	31		
Loam II			30	27								
1910	June	Aug.	Sept.				May	July	Sept.			
Loam I	13	17	8				34	56	42			
Loam II	34	55	59									
1911	May	June	July	Aug.	Sept.		May	June	July	Sept.		
Loam I	51	50	43	29	32·5		43·5	43	75	115		
Loam II	79	95	73	69	90							
1912	Jan.	April	May	June	July	Sept.	Feb.	April	May	June	July	Sept.
Loam I	9	20	24	30·5	19	17	31	18	34	45·5	48	23
Loam II	8·5	23	22	45	32	22						

NOTE.—In reducing parts per million to lbs. per acre the following weights of fine earth (dry) in millions of lbs. per acre were taken :—

	Milbrook sand	Ridgmont clay	Ridgmont loam
0—9″	2·80	2·45	2·99
9—18″	2·58	2·35	3·35

These figures were kindly supplied by Mr Pickering.

Rothamsted soils.

	Broadbalk, Orchard	Broadbalk plots		Hoosfield barley plots		Hoosfield wheat, fallow plot
		Dunged plot	Others	Dunged plot	Others	
0—9″	2·58	2·51	2·59	2·08	2·53	2·65
9—18″	2·56	2·67	2·67	2·59	2·59	2·70

TABLE II. *Effect of manures on nitrate content.*

Uncropped land. Season 1912. Hoosfield Barley plots left fallow. Nitrogen as nitrate.

Nitrogen as nitrate, parts per million of dry soil

Usual Manure	Plot No.	Feb. 15 0—9″	Feb. 15 9—18″	Mar. 12 0—9″	Mar. 12 9—18″	Mar. 26 0—9″	Mar. 26 9—18″	Apr. 10 0—9″	Apr. 10 9—18″	Apr. 19 0—9″	Apr. 19 9—18″	Apr. 30 0—9″	Apr. 30 9—18″	May 13 0—9″	May 13 9—18″	May 22 0—9″	May 22 9—18″	June 26 0—9″	June 26 9—18″	July 22 0—9″	July 22 9—18″	Sept. 26 0—9″	Sept. 26 9—18″	Feb. 4, '13 0—9″	Feb. 4, '13 9—18″
No manure	Fallow	6	5	4	5	5	3	5	5	7	4	5	5	5	4	4	4	9	7	8	10	5	3	4	4
Amm. salts	1 A	5	5	5	4	4	3	6	5	8	7	8	6	7	5	10	7	14	11	16	11	6	6	4	4
Do. + complete minerals	4 A	5	6	4	6	6	4	7	7	6	7	7	6	7	6	6	4	9	12	14	9	7	8	3	3
Dung	7^2	9	7									15	15	18	12	12	13	28	19	30	19	16	19	6	6

lbs. per acre, 0—18″

Usual Manure	Plot No.	Feb. 15 0—18″ lb.	Mar. 12 0—18″ lb.	Mar. 26 0—18′ lb.	Apr. 10 0—18″ lb.	Apr. 19 0—18″ lb.	Apr. 30 0—18″ lb.	May 13 0—18″ lb.	May 22 0—18″ lb.	June 26 0—18″ lb.	July 22 0—18″ lb.	Sept. 26 0—18″ lb.	Feb. 4, '13 0—18″ lb.
No manure	Fallow	28	24	19	25	29	27	23	22	39	45	19	20
Amm. salts	1 A	25	22	17	30	37	38	31	43	64	71	28	19
Do. + complete minerals	4 A	28	26	25	34	33	32	33	25	56	58	36	16
Dung	7^2	38					69	68	58	105	110	83	27

The plots being fallowed this year no manure was applied during the whole period; the last lot of ammonium salts were put on for the preceding crop in Feb. 1911, and the last dung (14 tons) was applied to 7^2 at the same time.

TABLE II (*cont.*).

Cropped land. Wheat season, 1912. Broadbalk. Nitrogen as nitrate.

Parts per million of dry soil

Usual Manure	Plot No.	Feb. 29		Mar. 12		Mar. 22		Apr. 10		Apr. 19		Apr. 30		May 13		May 22		June 26		Sept. 26		Feb. 4, '13	
		0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″
No manure	3	4	4	4	5	4	3	5	6	5	5	—	—	4	5	7	9	5	1	5	3	3	4
Double amm. salts	10	7	5	5	3	4	3	10	8	9	10	12	7	14	16	31	17	19	12	4	6	3	4
Do. + minerals	7	6	8	6	6	4	4	9	4	7	3	13	10	8	9	17	15	9	—	8	6	6	6
Dung	2	12	9	16	4	6	8	10	10	11	9	4	8	12	11	16	16	10	8	10	6	10	7

lbs. per acre 0—18″

Usual Manure	Plot No.	Feb. 29	Mar. 12	Mar. 22	Apr. 10	Apr. 19	Apr. 30	May 13	May 22	June 26	Sept. 26	Feb. 4, '13	Nitrogen in crop, lbs. per acre
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	
No manure	3	23	24	17	27	26	—	23	42	17	21	20	7·6
Double amm. salts	10	31	21	18	48	51	49	77	124	81	27	18	6·2
Do. + minerals	7	35	32	22	35	26	61	46	83	24	38	31	13·1
Dung	2	54	50	35	49	48	31	56	82	44	40	41	32·3

The ammonium salts were applied in two dressings, one fourth (containing 21·5 lbs. N) on Sept. 26—27, 1911, and the remainder (containing 64·5 lbs. N) on March 27, 1912. The dung (14 tons, containing 200 lbs. N) was applied on Sept. 15, 1911.

TABLE II (*cont.*).

Season 1909. Broadbalk Wheat plots. Nitrogen as nitrate.

Manure	Parts per million of dry soil 0—9″					lbs. per acre 0—9″			
	Plot No.	Apr. 6	May 7	July 6	Oct. 28	Apr. 6	May 7	July 6	Oct. 28
						lb.	lb.	lb.	lb.
Double amm. salts	10	6	16	3	6	14	42	8	16
Do. + minerals	7	8	16	3	10	21	42	9	27

Ammonium salts applied one quarter (21·5 lbs. N) on Oct. 7, 1908, and the rest (64·5 lbs. N) on April 7, 1909.

Season 1909. Hoosfield Barley plots. Nitrogen as nitrate.

Manure	Parts per million of dry soil 0—9″					lbs. per acre 0—9″			
	Plot No.	Apr. 6	May 7	July 6	Oct. 28	Apr. 6	May 7	July 6	Oct. 28
						lb.	lb.	lb.	lb.
Unmanured	1 O	6	—	3	3	15	—	7	8
Amm. salts	1 A	13	9	2	3	33	23	4	9
Super + amm. salts	2 A	—	13	3	3	—	33	8	7
Amm. salts + complete minerals	4 A	15	10	3	3	37	26	9	8
Dung	7[2]	22	21	4	6	46	43	7	12

Ammonium salts (43 lbs. N) applied Feb. 20, 1909, and dung (200 lbs. N) on Feb. 22, 1909.

Season 1911.

Manure	Parts per million of dry soil						lbs. per acre			Nitrogen in crop, lbs. per acre
	Plot No.	May 17		June 8		Sept. 13	May 17	June 8	Sept. 13	
		0—9″	9—18″	0—9″	9—18″	0—9″	lb.	lb.	lb.	
Unmanured	1 O	7	7	6	4	7	35	25	18	8
Amm. salts	1 A	7	8	6	10	8	40	42	20	21
Super + amm. salts	2 A	12	14	11	12	7	67	59	18	24
Amm. salts + complete minerals	4 A	12	14	9	10	5	67	49	13	34
Dung	7[2]	17	7	12	13	9	53	58	18	37

Ammonium salts (43 lbs. N) applied Feb. 18, 1911, and dung (200 lbs. N) on Feb. 14, 1911.

TABLE II (*cont.*).

Season 1910. Barnfield Mangolds. (These being sown late the land is practically fallow till the middle of June.)

Manure	Parts per million of dry soil 0—9″		lbs. per acre 0—9″	
	June 4	July 27	June 4	July 27
Unmanured	4·5	3	12	8
Super only	6·5	2	17	5
Super + potassium salts	5	2	13	5
Super + magnesium and sodium salts	5	2	13	5
Super + potassium, mag. and sodium salts	4	2·5	10	7
Dung*	24·5	7	56	16
Dung + potassium salts*	37	4	85	9

* The dung was applied April 11, 1910.

Losses during summer and winter. A wet autumn or winter has a disastrous effect on the nitrates in loams and sands. At the end of the fine season of 1911 a considerable store of nitrate had accumulated, but a great proportion was lost during the wet winter that followed:—

	Rainfall during period, ins.	N. as nitrate: Parts per million				N. as nitrate: lbs. per acre	
		Broadbalk orchard		Hoos fallow		Broadbalk orchard	Hoos fallow
		0—9″	9—18″	0—9″	9—18″	0—18″	0—18″
Sept. 13, 1911	19·91	23	22	13	7	115	51
Feb. 15, 1912		7	5	5	4	31	28
		Ridgmont loam (105)		Milbrook sand (21)		Ridgmont loam (105)	Milbrook sand (21)
Sept. 7, 1911	11·67	17	14	6	4	97	29
Jan. 15, 1912		2	1	2	2	7	10

The loss, however, was much less on the clay soil:—

	Parts per million		lbs. per acre
	0—9″	9—18″	
Sept. 7, 1911	19	9	67
Jan. 13, 1912	11	12	56

Equally serious losses occur in a wet autumn. The results obtained in 1912 were:—

	Rainfall in intervening period	N. as nitrate, parts per million in uncropped land. Hoosfield *, 1912.							
		Dung 7[2]		Artificial manures				Unmanured †	
				1 A		4 A			
		0—9″	9—18″	0—9″	9—18′	0—9″	9—18″	0—9″	9—18″
Summer, July 22		30	19	16	11	14	9	8	10
Autumn, Sept. 26	9·00	16	19	6	6	7	8	4	3
Late winter, Feb. 4	14·70	6	6	4	4	3	3	4	3

* The Hoosfield barley plots which were fallowed during the season of 1912 (see p. 27).
† The fallow portion of the wheat plots.

	N. as nitrate, lbs. per acre			
	Dung 7[2]	Artificial manures		Unmanured
		1 A	4 A	
	0—18″	0—18″	0—18″	0—18″
Summer, July 22	110	71	58	45
Autumn, Sept. 26............	83	28	36	19
Late winter, Feb. 4	27	19	16	20

The amount of loss depends on the wetness of the period. The driest winter during the period was that of 1908—09, and the wettest was that of 1911—12. We find higher values for the nitrates in all the soils in March 1909 than in April 1912. The wetness of the winter may be approximately estimated from the rainfall and the number of days on which the drain gauges ran; the figures are as follows:—

Year	Wetness of preceding winter (Oct.—March)		Nitrate, lbs. per acre in top 18″ in spring			
	Rainfall in inches	No. of days on which drain gauges ran	Sand	Clay	Loam	
					Ridgmont	Rothamsted
1909	10·29	32	25	47	28	21
1912	23·56	80	19	29	21	18

The effect of the wet winter persisted and the May maximum of 1912 is lower than that of any other year.

2. *Cropped land.* The effect of a crop is to reduce considerably the amount of nitrate in the soil. On plots of cereals the amount usually falls from about May right through to the time of harvest; in the case of mangolds the fall begins rather later[1]. When a cropped plot is compared with a fallow plot there is a steadily increasing difference from spring to autumn, as shown in the following figures:—

Nitrate in adjoining fallow and cropped plots.

Broadbalk orchard*, 1911	May 7		June 8		July 27	
	A	B	A	B	A	B
Fallow, parts per mill., top 9″	11	10	10	7	21	15
9—18″	5	9	8	7	15	13
lbs. per acre, 0—18″.........	40	50	46	35	93	72
Cropped (Lucerne and grass) parts per million, top 9″ ...	6	8	4	4	8	11
9—18″...	6	5	2	4	5	9
lbs. per acre, 0—18″	31	32	16	20	35	49

* This land was a lucerne ley from 1905—1908, the part called fallow was then dug up and in 1909 planted with small fruit trees. A and B are at the extreme ends of the plot. No manure was added.

Hoosfield wheat plots, 1911	April 21	May 17	June 8	Sept. 13
Fallow, parts per mill., top 9″	10	7	12	13
9—18″	—	5	9	7
lbs. per acre, 0—18″.........	(27)*	33	55	54
Cropped (Wheat), parts per million, top 9″	9	6	4	5
9—18″...............	—	5	2	—
lbs. per acre, 0—18″.........	(23)*	30	15	13

* 0—9″ only.

[1] On June 4th, 1910, the dunged mangold plots 1—0 and 2—0 contained respectively 16 and 19 parts of nitrogen as nitrate per million of soil; by July 27th these amounts were reduced to 7 and 5 respectively.

1912	Feb. 15	Mar. 12	Mar. 26	Apr. 10	Apr. 19	Apr. 30	May 13	May 22	June 26	July 22	Sept. 26	Feb. 4, 1913
Fallow, parts per million, top 9″	6	4	5	5	7	5	5	4	9	8	5	4
9—18″	5	5	3	5	4	5	4	4	7	10	3	4
lbs. per acre, 0—18″	28	24	19	25	29	27	23	22	39	45	19	20
Cropped (Wheat), parts per million, top 9″	5	4	5	5	6	3	7	5	5	2	3	4
9—18″	4	6	3	3	3	4	5	4	4	3	3	4
lbs. per acre, 0—18″	24	25	19	22	24	18	31	24	22	13	16	21

No manure is applied to these Hoosfield plots.

The difference during June and July is seen to be great; the cropped plots in Broadbalk contained 23 and 58 lbs. per acre less than the fallow land, and that in Hoosfield contained 40 lbs. less in 1911 and 32 lbs. in 1912.

Thus the cropped land tends to contain a minimum amount of nitrate at harvest time and there is less difference than might be expected in different seasons on the same land. The results obtained by Warington[1] in October 1881 and October 1893 are of the same order as those obtained on the same plots in 1912 :—

Plot		N. as nitrate in lbs. per acre, 0—18″		
		Oct. 1881	Oct. 1893	Sept. 26, 1912
3 & 4	Unmanured	14	17	21
10	Ammonium salts only	24	38	27
7	Amm. salts + complete minerals	32	34	38
2 B	Dung	44	56	40

After the harvest the amounts of nitrate may rise: thus in 1909 two of the Broadbalk plots yielded the following results in comparison with a fallow unmanured plot:—

[1] Warington, R., "Lost Fertility: the Production and Loss of Nitrates in the Soil," *Trans. Highland Agric. Soc.* 1905, **17** (5th series), 148-181.

	Parts per million					lbs. per acre				
	April, 0—9″	May, 0—9″	July, 0—9″	Oct., 0—9″	Oct., 9—18″	April, 0—9″	May, 0—9″	July, 0—9″	Oct., 0—9″	Oct., 0—18″
Cropped plots										
Plot 10 Ammonium salts only	6	16	3	6	3	14	42	8	16	—
,, 7 Ammonium salts + complete minerals	8	16	3	10	3	21	42	9	27	36
Fallow plot										
Young fruit trees only, no manure	4	8	6	5	7	11	20	16	14	31

In July the cropped plots contained very little nitrate, only about half as much as the uncropped plot. But a month after the harvest was over the nitrate had increased so much in amount that it exceeded that present on the uncropped plot, there being 36 lbs. per acre in the top 18 inches against 31 lbs. Similar increases were obtained in 1913 on the dunged but not on the unmanured plots:—

N. as nitrate, parts per million

	Before harvest	After harvest 17 days	After harvest 6 weeks
Broadbalk plots			
Unmanured	6	8	6
Dunged	7	14	17

The fate of the nitrates on the cropped plot. The preceding paragraphs have shown the marked difference in nitrate content between a cropped and an uncropped piece of land. One obvious reason for the difference is that the crop absorbs some of the nitrate. It does not appear, however, that this is the sole factor involved, for even after allowing for the nitrogen in the crop there is still a deficit as compared with the fallow land. This is well seen on Hoosfield, where two adjacent strips of land are alternately cropped with wheat and left fallow for a year, both being unmanured. The nitrate found on these strips in lbs. per acre was as follows:—

	In 1911		In 1912	
	Fallow land	Cropped land	Fallow land	Cropped land
N. as nitrate in top 18″ of soil, June	53·7	15·3	46·1	12·8
Nitrogen in crop		22·6*		6·1*
Total.........	53·7	37·9	46·1	18·9
Deficit in cropped land		15·8		27·2

* The nitrogen in the crop was obtained as follows:—

	Straw			Grain			Total N. in straw and grain, lbs. per acre
	Crop, lbs. per acre	N., per cent.	N., lbs per acre	Crop, lbs. per acre	N., per cent.	N., lbs. per acre	
1911	1535	0·36	4·7	1152	1·78	17·9	22·6
1912	706	0·43	2·4	266	1·67	3·7	6·1

It is impossible to say how much of the excess of nitrate on the fallow land of 1911 arises from the stubble left over from 1910, when the cropped land of 1911 was lying fallow and therefore carrying no stubble. So with the fallow strip of 1912, which had been the cropped strip of 1911. But the whole straw only contains 3 or 4 lbs. of nitrogen, and the stubble certainly contains no more than this if as much, while the deficit to be accounted for is 16 lbs. in 1911 and 27 lbs. in 1912. Nor does leaching account for the difference, because the loss by leaching is greatest on the fallow strip. Whatever the explanation, the fact remains that cropped land contains less nitrate by the end of the season than fallow land, even after allowance has been made for the nitrate taken up by the crop.

We can even go further. No evidence could be obtained that the cropped soils gained in nitrates after the early summer. When the nitrogen as nitrate contained in the top 18 inches of soil at the end of the season (Aug. or Sept.) is added to that in the crop the sum is not more than the stock present in May. The following results were obtained in 1911 on the Hoosfield barley plots:—

	Ammonium salts only, 1 A		Dung 7[2]	
Nitrate in soil in May............	40		53	
,, ,, Sept.		20		18
Nitrogen in crop		21		37
Balance to be accounted for ...	1		2	
Total.........	41	41	55	55

Here the amount of nitrogen accounted for in September is approximately equal to the amount present in May. But in other cases it is not even equal; the September amounts do not balance those found in May and some other source of loss must come into play to account for the deficit:—

	Hoos Barley, 1911						Hoos wheat, 1912 Unmanured	
	Unmanured		Amm. salts + super, Plot 2 A		Amm. salts + complete minerals, Plot 4 A			
Nitrate in soil (0—18″) in May	35		67		67		31	
,, ,, ,, Sept.		18		18		13		16
Nitrogen in crop		8		24		34		6
Balance to be accounted for ...		9		25		20		9
Total.........	35	35	67	67	67	67	31	31

	Broadbalk wheat, 1912						Dung, Plot 2 b	
	Unmanured, Plot 3		Amm. salts alone, Plot 10		Amm. salts + complete minerals, Plot 7			
Nitrate in soil (0—18″) in May	42		124		83		82	
,, ,, ,, Sept.		21		27		38		40
Nitrogen in crop		8		6		13		32
Balance to be accounted for ...		13		91		32		10
Total	42	42	124	124	83	83	82	82

In 1912 the Broadbalk plots were exceedingly foul and an unknown fraction of the missing nitrogen was removed in the weeds. Owing to the wetness of the season a certain amount of leaching took place also. It is less easy to account for the loss on Hoosfield in 1911. The important point, however, is that in no case is there more nitrate in the soil *plus* crop in autumn than there was in spring, and generally there is less.

It cannot be argued from these results that an actual loss of nitrate is brought about by the activity of the plant roots because we have no certain knowledge that the barley roots can forage so deeply as 18 inches, the depth to which the nitrate has been taken into account. Indeed if we confine ourselves to a depth of 9 inches then the crop usually obtains more than is lost from this thickness of soil:—

	Broadbalk, 1909 Amm. salts + complete minerals		Hoos barley plots, 1909: Un-manured, Plot 1—0		Hoos barley plots, 1909: Amm. salts + super, Plot 2 A		Hoos barley plots, 1909: Amm. salts + complete minerals, Plot 4 A		Dung 7^2	
Nitrate in soil (0—9″) in May...	42		15		33		37		46	
,, ,, ,, Sept....		9		7		8		9		7
Nitrogen in crop		44		14		38		48		71
Balance to be accounted for ...	11		6		13		20		32	
Total.........	53	53	21	21	46	46	57	57	78	78

The Hoos barley plots, 1—0, 1—A, and 7^2, generally give similar results. In a few cases (Hoos barley 1 A of 1909 and 2 A of 1910) the amount in the crop almost equals the quantity lost from the soil, but on Broadbalk Plot 10 it is less:—

	Broadbalk, 1909 Amm. salts only (Plot 10)		Hoos barley plots: 1909 Amm. salts only (Plot 1 A)		Hoos barley plots: 1910 Amm. salts + super (Plot 2 A)	
Nitrate in soil (0—9″) in May...	42		33		42	
,, ,, ,, July...		8		4		9
Nitrogen in crop		22		27		30
Balance to be accounted for ...		12		2		3
Total.........	42	42	33	33	42	42

The results may be briefly summed up as follows :—The quantity of nitrate found in the top 18 inches of a cropped soil in late summer was no greater than was present in late spring even after allowing for what had been taken by the crop. This is not true of fallow soils; here more nitrate was found in late summer than late spring even in a bad year such as 1912 (Table II). The significance of these results will be discussed later.

Effect of manuring. As already stated, nitrate production is the quickest of the stages in the decomposition of organic matter so that ammonia does not accumulate in the soil under normal conditions. But the case is rather different when ammonium salts are added to the soil. Part of the ammonia enters into some stable combination from which it is not dislodged by heating with magnesia[1], but much of it remains as an ammonium compound and can be detected in the usual way; this part survives for some time. Ammonium salts applied in the February of 1909 were not completely converted into nitrate even at the end of seven weeks, but quantities applied later on (April 5th) were practically completely nitrified in four weeks :—

Plot	Date of application of amm. salts	N. present as NH_3 after			N. present as nitrate after		
		44 days (April 6)	75 days (May 7)		44 days (April 6)	75 days (May 7)	
Hoos barley 4 A	Feb. 20 and 21, 1909	13	2		15	10	
1 A	,,	4	2		13	9	
		1 day (Apr. 6)	32 days (May 7)	92 days (July 6)	1 day (Apr. 6)	32 days (May 7)	92 days (July 6)
Broadbalk 7	April 5, 1909	19	5	4	8	16	3
,, 10	,, ,,	13	3	1·5	6	16	3

Parts per million of dry soil.

In 1912 the process was slower and ammonium salts added on March 27 were still yielding nitrates in the latter half of May (Table II).

Effect of potassic and phosphatic manures. Determinations have been made on the plots which for many years have received neither potassium salts nor phosphates to ascertain whether a deficiency of

[1] Russell, this *Journal*, 1910, **3**, 241.

these substances would retard the process of nitrification. Reference to Table II shows that such an effect was produced only in 1911; in the other years there is nothing to show that these particular organisms are affected although plants suffer to a marked degree from potash and phosphate starvation. Indeed in 1912 and 1913 there was more nitrate on the plots supplied with ammonium salts only than where potassium salts and phosphates are given. In 1912 the land lay fallow, but in 1913 it carried a barley crop which however was much larger on the completely fertilised plot than on the others.

Residual effect of ammonium sulphate. In 1912 the Hoosfield plots were fallowed and no manures were applied. It was found that the plots which regularly receive ammonium salts contained a higher proportion of nitrate than the unmanured plot (Table II). To some extent this may arise from the decomposition of the stubble which, being increased in amount by addition of ammonium salts, yields larger amounts of nitrate on decomposition. There appears, however, to be some other factor involved, because Plot 1 A, receiving ammonium salts only, contained *more* nitrate than Plot 4 A, which receives in addition potash and phosphates, although it always has a *smaller* crop. In the preceding year (1911) it had contained less nitrate than 4 A besides yielding a smaller crop. These results strongly suggest that some of the ammonium salts had been held over in some form or other from 1911 till 1912.

The possibility of such an action has been investigated on the Broadbalk wheat field[1]. Two plots (Nos. 17 and 18) side by side receive ammonium salts only in alternate years, so that each year one has a dressing and the other has not. A third plot (No. 5) receives the same mineral manures but no nitrogen manure at any time. The average results for the past sixty years have been :—

Plots		Total produce, lbs. per acre	Grain, bushels per acre
17 & 18	Years when ammonium salts are supplied ...	1354	29·9
	Years when no ammonium salts are supplied	842	14·9
5	No nitrogenous manure since 1852	799	14·5

Thus the omission of ammonium salts for a single year brings down the crop nearly to the level of Plot 5 showing that only a small residue

[1] A similar experiment has been made at Woburn and a distinct residual effect is obtained.

is left behind from the preceding year. Nitrate determinations lead to the same conclusion. The amounts of nitrogen as nitrate found on April 18th, 1913, were:—

Plots		Parts per million		lbs. per acre, 0—18″
		0—9″	9—18″	
5	Mineral manures only	4·5	5	25
17	Mineral manures + amm. salts in March, 1912	6·5	6	33
18	,, ,, ,, ,, 1913	11	5	42

The differences here are much smaller than in Hoosfield.

The Effect of Fluctuations in Nitrate Content on the Crop.

The relation between the amount of nitrate in the soil and the amount of crop growth is in the main fairly simple. So long as there is sufficient potash and phosphate in the soil the crop increases with the nitrate supply until some limiting factor (such as water supply, temperature, etc.) intervenes and puts an end to further growth. The factors that regulate the amount of nitrate in the soil are therefore controlling factors in crop production. Since, however, their action is on the nitrate and not on the crop we cannot expect to find them closely and immediately related to the amount of crop growth: nevertheless over an average of years their action is plainly indicated.

The foregoing experiments have brought out the following conclusions:—

1. Nitrates are rapidly produced in spring or early summer.

2. Unless absorbed by a crop they remain in the soil and tend to increase in amount during a dry summer.

3. They are more largely removed during a wet winter than in a dry winter.

4. Nitrates are present in greatest amount in spring when the preceding winter and summer have been dry: they are on the other hand present in smaller quantity when the preceding winter has been wet. If the preceding summer has been dry so that nitrate accumulation went on to a considerable extent the loss during winter is proportionately greater.

A study of the Rothamsted data shows that the operation of these relationships can be readily traced in the growth of the crop. In particular the loss of nitrates during a wet winter has a marked effect, as shown in Tables III and IV. Two sets of experiments illustrate

TABLE III. *Effect of Autumn and Winter rainfall on Soil Nitrates as illustrated by yield of Wheat. Broadbalk Field.*

Comparison of Spring and Autumn dressings of ammonium salts.

Year when crop was reaped	Rainfall of preceding autumn and winter (Oct. to March)	Total produce, lbs. per acre				Grain, bushels per acre			
		Ammonium salts applied		Difference in favour of spring dressing		Ammonium salts applied		Difference in favour of spring dressing	
		in previous autumn Plot 15	in spring Plot 7	per acre	per cent.	in previous autumn Plot 15	in spring Plot 7	per acre	per cent.
(A) Years of LOW winter rainfall									
1889	12·35	4422	5149	+ 727	+16·4	27·0	30·7	+3·7	+13·7
1890	12·83	6631	5806	− 825	−12·4	40·8	36·0	−4·8	−11·8
1891	8·98	6633	7596	+ 963	+14·5	38·9	40·6	+1·7	+ 4·3
1893	13·76	2377	2614	+ 237	+ 9·9	18·5	20·3	+1·8	+ 9·7
1898	8·46	7043	6924	− 119	− 1·6	30·0	28·4	−1·6	− 5·3
1901	13·85	4579	4339	− 240	− 5·2	29·8	29·6	−0·2	− 0·6
1902	10·76	6560	6727	+ 167	+ 2·5	39·6	38·2	−1·4	− 3·5
1903	12·28	3221	4817	+1596	+49·5	20·2	26·6	+6·4	+31·7
1905	11·37	7285	8037	+ 752	+10·3	37·5	40·7	+3·2	+ 8.5
1906	14·05	6984	6238	− 746	−10·6	42·2	37·7	−4·5	−10·6
1909	10·29	6212	5867	− 345	− 5·5	25·8	28·9	+3·1	+12·0
Mean	11·73	5631	5829	+ 196	+ 3·4	31·8	32·5	+0·7	+ 2·2
(B) Years of HIGH winter rainfall									
1892	16·85	4702	5240	+ 538	+11·4	28·6	32·0	+3·4	+11·8
1894	16·54	7677	9144	+1467	+19·1	40·4	48·4	+8·0	+19·8
1895	14·94	3517	4519	+1002	+28·4	25·1	32·2	+7·1	+28·2
1896	15·45	4977	6204	+1227	+24·6	30·8	37·2	+6·4	+20·7
1897	19·08	3478	5030	+1552	+44·6	20·5	28·6	+8·1	+39·5
1899	14·61	5283	6503	+1220	+23·0	26·9	31·3	+4·4	+16·3
1900	18·45	3281	4793	+1512	+46·0	20·2	29·8	+9·6	+47·5
1907	16·34	7654	8516	+ 862	+11·2	33·1	33·6	+0·5	+ 1·5
1908	17·04	4995	5607	+ 612	+12·2	32·3	33·3	+1·0	+ 3·0
1910	17·04	4533	5633	+1100	+24·2	20·4	25·6	+5·2	+25·4
1911	17·63	4154	4854	+ 700	+16·8	24·1	25·6	+1·5	+ 6·2
Mean	16·73	4932	6004	+1072	+21·7	27·5	32·5	+5·0	+18·1

TABLE IV. *Effect of Winter rainfall on Soil Nitrates as illustrated by yield of Wheat.*

Comparison of wheat grown continuously with wheat grown after fallow.

Year when crop was reaped	Rainfall of preceding autumn and winter (Oct. to March)	Total produce, lbs. per acre: Unmanured: Plot 3 Broadbalk, continuous	Total produce, lbs. per acre: Unmanured: Plot O after fallow	Total produce: Difference in favour of growing after fallow: per acre	Total produce: Difference in favour of growing after fallow: per cent.	Grain, bushels per acre: Unmanured: Plot 3 Broadbalk, continuous	Grain, bushels per acre: Unmanured: Plot O after fallow	Grain: Difference in favour of growing after fallow: per acre	Grain: Difference in favour of growing after fallow: per cent.
(A) Years of LOW winter rainfall									
1889	12·35	1645	1712	+ 67	+ 4·1	12·2	13·1	+0·9	+ 7·4
1890	12·83	1853	2745	+ 892	+ 48·1	14·0	17·8	+3·8	+27·1
1891	8·98	2143	3645	+1502	+ 70·1	13·8	23·1	+9·3	+67·4
1893	13·76	1251	1724	+ 473	+ 37·8	9·8	13·5	+3·7	+37·8
1898	8·46	2186	3964	+1778	+ 81·3	12·0	20·2	+8·2	+68·3
1901	13·85	1627	2062	+ 435	+ 26·7	11·7	14·7	+3·0	+25·6
1902	10·76	1853	3729	+1876	+101·2	13·3	22·4	+9·1	+68·4
1903	12·28	1078	2111	+1033	+ 95·8	7·6	14·0	+6·4	+84·2
1905	11·37	3456	2596	− 860	− 24·9	18·0	12·9	−5·1	−28·3
1906	14·05	2156	2340	+ 184	+ 8·5	15·2	13·4	−1·8	−11·8
1909	10·29	1633	2326	+ 693	+ 42·4	9·1	12·9	+3·8	+41·8
Mean	11·732	1898	2632	+ 734	+ 38·7	12·4	16·2	+3·8	+30·6
(B) Years of HIGH winter rainfall									
1892	16·85	1425	1839	+ 414	+ 29·1	9·3	11·7	+2·4	+25·8
1894	16·54	2608	2436	− 172	− 6·6	18·0	15·5	−2·5	−13·9
1895	14·94	1384	2129	+ 745	+ 53·8	10·0	15·5	+5·5	+55·0
1896	15·45	2396	2332	− 64	− 2·7	16·8	16·1	−0·7	− 4·2
1897	19·08	1459	1170	− 289	− 19·8	8·8	7·1	−1·7	−19·3
1899	14·61	1825	2620	+ 795	+ 43·6	12·0	15·7	+3·7	+30·8
1900	18·45	1776	1801	+ 25	+ 1·4	12·3	11·9	−0·4	− 3·3
1907	16·34	1715	3094	+1379	+ 80·4	9·1	14·3	+5·2	+57·1
1908	17·04	1671	1083	− 588	− 35·2	12·4	7·2	−5·2	−42·0
1910	17·04	1553	1747	+ 194	+ 12·4	7·5	9·3	+1·8	+24·0
1911	17·63	1935	2687	+ 752	+ 38·9	12·5	17·0	+4·5	+36·0
Mean	16·73	1795	2085	+ 290	+ 16·2	11·7	12·8	+1·1	+ 9·4

this point very clearly; one on Broadbalk where the effect of autumn application of sulphate of ammonia is contrasted with that of spring applications, and the other in Hoosfield, where a wheat crop is taken after a bare fallow. Plots 7 and 15 on the Broadbalk wheat field each receive the same complete mineral and ammonium salts, but on Plot 7 the ammonium salts are applied in spring and on Plot 15 they are applied in autumn. In years of low winter rainfall there is on an average practically no difference in yield, but in years of high winter rainfall the autumn dressings give considerably poorer results than the spring dressings.

The Hoosfield experiment enables us to compare the yield of wheat on land where it grows every year with that on land where it grows alternate years only, the intervening years being fallow. When there is no crop on the ground the nitrates accumulate to a notable extent (see p. 32), and if they remain till the following spring they increase the yield of wheat over and above what is obtained under continuous cropping. But if the winter has been wet much of the advantage is lost and the difference between the plots becomes considerably less. The data are given in Table IV, and it is seen that on an average after dry winters the crop preceded by a fallow is 38 per cent. higher than that preceded by another crop, but after wet winters it is only 16 per cent. higher.

A hot dry summer followed by a mild wet winter is, as we have seen, unfavourable to nitrate accumulation. The data collected in Table V show that the crop is adversely affected. Of the two Broadbalk plots 2 B receives farmyard manure every year and the plant is therefore dependent on nitrification for its nitrogenous food, while 16 receives a complete artificial manure containing more than enough nitrate of soda to supply nitrogen for the plant. On an average over the whole period during which the years were selected (1874—1912) the crops on the two plots are almost alike, being 6374 lbs. of total produce per acre on Plot 2 B and 6540 on Plot 16. But when the season has been preceded by a dry winter and this in turn by a dry summer the returns from the dunged plot are at a maximum, averaging 7537 lbs. per acre against 6375 lbs. from the plot with artificial manures, a difference of 1162 lbs. per acre in favour of dung. This is when the conditions are favourable for nitrate accumulation. When the preceding winter has been wet and the summer dry, i.e. when the conditions become unfavourable for nitrate accumulation, the position is reversed: farmyard manure now gives a much inferior crop of 5709 lbs. per acre, while the artificial manures give 6635 lbs., a difference of 926 lbs. in favour of the artificial manures. The result of course cannot be wholly attributed

TABLE V. *Effect of winter rainfall after dry summers. Yield of wheat on Broadbalk field.*

Year when crop was reaped	No. of days the drain gauges ran during: summer of preceding year (July—Sept.)	No. of days the drain gauges ran during: preceding winter (Oct.—March)	Rainfall of: summer of preceding year (July—Sept.)	Rainfall of: preceding winter (Oct.—March)	Yield of wheat, total produce per acre, lbs.: Broadbalk, Dunged 2 b	Yield of wheat, total produce per acre, lbs.: Broadbalk, Plot 16 (complete artificials)	Yield of wheat, total produce per acre, lbs.: Difference in favour of dung	Yield of wheat, total produce per acre, lbs.: Broadbalk unmanured Plot 3 continuous	Yield of wheat, total produce per acre, lbs.: Hoosfield ½ acre after fallow	Yield of wheat, total produce per acre, lbs.: Difference in favour of fallow	Yield of grain, bushels per acre: Broadbalk, Dunged 2 b	Yield of grain, bushels per acre: Broadbalk, Plot 16 (complete artificials)	Yield of grain, bushels per acre: Difference in favour of dung	Yield of grain, bushels per acre: Broadbalk unmanured Plot 3 continuous	Yield of grain, bushels per acre: Hoosfield ½ acre after fallow	Yield of grain, bushels per acre: Difference in favour of fallow
							Crops preceded by dry summers and wet winters									
1874	14	124	7·41	9·84	6870	7421	- 551	1684	3370	1686	39·3	38·2	+ 1·1	11·4	21·5	10·1
1875	8	107	8·17	13·40	5609	6712	- 1103	1575	2718	1143	28·8	30·5	- 1·7	8·6	16·1	7·5
1877	22	158	9·45	21·36	3747	6235	- 2488	1291	1478	187	24·1	40·1	- 16·0	8·8	10·5	1·7
1881	35	98	12·18	19·32	4274	5911	- 1637	2009	1645	- 364	30·2	35·3	- 5·1	13·7	12·3	- 1·4
1882	23	87	9·74	16·06	5997	8286	- 2289	1774	1804	30	32·7	31·8	+ 0·9	10·9	11·8	0·9
1883	15	108	6·44	21·77	5174	8032	- 2858	1878	2461	583	35·2	43·3	- 8·1	13·8	18·1	4·3
1884	27	100	9·04	12·81	5504	7494	- 1990	1729	2784	1055	32·5	40·3	- 7·8	13·0	20·2	7·2
1885	23	81	6·21	14·10	6228	7210	- 982	2062	3163	1101	40·1	37·3	+ 2·3	15·3	23·0	7·7
1887	10	70	5·15	16·01	5699	6621	- 922	1801	2365	564	34·6	39·6	- 5·0	14·8	19·0	4·2
1897	25	89	12·25	19·08	6246	5476	+ 770	1459	1170	- 289	37·3	27·5	+ 9·8	8·8	7·1	- 1·7
1900	7	62	4·82	18·45	5871	6085	- 214	1776	1801	25	33·3	34·8	- 1·5	12·3	11·9	- 0·4
1911	11	47	6·26	17·63	6721	7565	- 844	1935	2687	752	36·7	40·4	- 3·7	12·5	17·0	4·5
1912	2	80	3·21	23·55	3416	2456	+ 960	942	972	30	18·1	10·7	+ 7·4	4·5	4·2	- 0·3
Means	17	93	7·72	17·18	5489	6577	- 1088	1686	2186	500	32·5	34·6	- 2·1	11·4	14·8	3·4
							Crops preceded by dry summers and dry winters									
1888	7	56	4·93	11·86	6363	6004	+ 359	1515	1974	459	38·0	33·8	+ 4·2	10·0	12·8	2·8
1898	8	31	6·14	8·46	8943	5397	+ 3546	2186	3964	1778	38·0	23·7	+ 14·3	12·0	20·2	8·2
1901	10	58	5·89	13·85	6435	4362	+ 2073	1627	2062	435	39·6	30·5	+ 9·1	11·7	14·7	3·0
1902	8	37	5·79	10·76	7708	5953	+ 1755	1853	3729	1876	41·5	33·5	+ 8·0	13·3	22·4	9·1
1903	9	60	5·82	12·28	5244	5077	+ 167	1073	2111	1038	29·7	26·8	+ 2·9	7·6	14·0	6·4
1905	9	44	6·66	11·37	8447	7676	+ 771	3456	2596	- 860	38·5	34·2	+ 4·3	18·0	12·9	- 5·1
1907	1	41	2·81	16·34	8992	9737	- 745	1715	3094	1379	36·2	34·7	+ 1·5	9·1	14·3	5·2
1909	9	32	7·00	10·29	8164	6794	+ 1370	1633	2326	693	33·8	26·9	+ 6·9	9·1	12·9	3·8
Means	8	45	5·63	11·90	7537	6375	+ 1162	1882	2732	850	36·9	30·5	+ 6·4	11·3	15·5	4·2
Means for whole period, 1874—1912	13	75	6·92	15·17	6269	6500	- 231	1761	2394	633	34·2	33·1	+ 1·1	11·4	15·1	3·7

to the character of the preceding summer and winter since the character of the season of growth obviously plays some part; but the latter effect is, as we have seen, largely smoothed out over the number of years.

It is important that agriculturists should realise what great accumulations of nitrate occur in the soil at the end of a dry summer and how complete may be the loss on loams and sands during a mild wet winter. The results on p. 30 show that 50 lbs. or more of nitrogen per acre may easily be lost while the land lies bare between harvest and seed time. Now 50 lbs. of nitrogen per acre is all that is taken out of the soil by a 32 bushel wheat crop. As the prices of nitrogenous manures go on rising it becomes more and more urgent that all waste of nitrogen should be cut down to a minimum; the problem therefore of reducing the winter loss is likely to increase in importance as time goes on.

An obvious method of attacking the problem is by green manuring, and experiments in this direction are being started.

The fact that clay soils retain their nitrates well during winter has already been demonstrated. This appears to be one of the reasons why clays are so suitable for wheat; it is known that wheat requires a supply of nitrates in early life and these are more likely to be present during winter on clay soils than on others.

Discussion of the Results.

On looking over the results the first point that comes out is the rapid accumulation of nitrates in late spring and early summer. During this period the balance of gains over losses is greater than at any other time.

A parallel result has been obtained by Leather at Pusa[1]. During the hot dry season (Oct.—May) relatively little nitrate was formed: after the first heavy rain in June a large increase took place and nitrate was rapidly produced in the first foot of soil: then the action slowed down very considerably and remained slow right on to the end of the wet season. Some of his results, expressed as lbs. of nitrogen per acre, are as follows:—

	Ap. 4	May 5	May 25	June 18	June 24	July 21	Aug. 10	Sept. 13
0—6″	·9	2·7	1·2	3·3	·5	·9	·9	·6
6″—12″	·7	·5	·7	18·3	12·8	1·5	·7	·6
12″—18″	·6	·5	·5	·7	6·3	12·0	·7	1·5
18″—24″	·9	·5	·4	·4	1·0	14·0	1·3	1·6

[1] Leather, J. W., "Records of Drainage in India." *Memoirs of the Dept. of Agric. in India*, 1912, II. 101.

C. A. Jensen[1] observed similar phenomena at Bellefourche, S. Dakota. In April only small amounts of nitrate were present in the soil: during the latter half of May and the early part of June a rapid accumulation takes place, but this soon falls off, and at no subsequent period is nitrate formation anything like so quick. Jensen suggests that the organisms have an active growing season of two or three weeks and then their physiological activity is reduced for some cause or other.

On looking over all the evidence the following general rule seems to emerge:—*When a period unfavourable to nitrification comes to an end and more favourable conditions set in, the rate of nitrate accumulation tends to be more rapid in the early part of this new period than later on.*

Several factors have to be taken into account in discussing this rule. In the first instance we know (p. 23) that the accumulation of nitrate ceases after a certain limit is reached, and it probably slackens before this stage. Thus in the dry summer of 1913 the land became so dry that the conditions were unfavourable for nitrification. A wet, warm September followed, when the conditions were distinctly favourable for nitrate production. Yet as a matter of fact little accumulation took place on the unmanured plots, probably because the limit was already reached. Accumulation was more marked on the dunged plots, but again it stopped at a certain point, which appears to be the maximum content for this plot:—

	Dry period		Moist period			Highest amount previously observed
	July 11	Aug. 29	Sept. 3	Sept. 22	Oct. 6	
Hoos fallow, N. as nitrate, parts per million	18	15	17	16	20	18
Moisture in soil, per cent.	8	4	14	12	14	
Broadbalk dunged plot, N. as nitrate, parts per million	7	14	12	17	18	16
Moisture, per cent.	11	10	17	16	13	

Thus these results probably form no real exception to the rule. Again, in interpreting our rapid accumulation in late spring it must be remembered that April, May and June are at Rothamsted somewhat drier than the succeeding months, the average rainfall (60 years) being

[1] Jensen, C. A., "Seasonal nitrification as influenced by crops and tillage." *U.S. Dept. of Agric., Bureau of Plant Industry*, Bull. 173, 1910.

6·48 inches while during the months July, August and September it is 7·56 inches. Further, the winter frosts may cause a certain amount of physical disintegration of the organic matter and render some of it easily assailable by the soil bacteria. Some of the organic matter probably yields ammonia more readily than the rest; while any easily decomposable manures added in spring would obviously give rise to nitrates at an early date. Besides all these possibilities (which affect the decomposable nitrogen compounds) there is another, viz. that the soil bacteria themselves may be more active in the earlier part of the favourable season than later on, or, in our particular case, more active in the spring than in summer and autumn.

Determinations of nitrates do not enable us to decide the question, but investigations made elsewhere seem to indicate that the bacterial activity may be at a maximum in late spring. Löhnis and Sabaschnikoff[1] have shown that the power of decomposing urea and cyanamide shown by the soil at Leipzig is most rapid in spring, then falls off in summer, but rises again in September. The curves obtained resemble my sand curve in Fig. 1. The nitrifying power, ammonifying power, nitrogen-fixing power, and to a less extent the denitrifying power of the soil showed the same type of variation with the season. Müntz and Gaudechon[2] maintain that the nitrifying power of soil is at a maximum in spring. They speak very picturesquely of the awakening of the soil in spring and consider it "une accoutumance, vrai fait d'atavisme" on the part of the soil bacteria. The details of their experiments are open to some criticism[3] but the general result seems to agree with Löhnis' and my own.

It is unnecessary to assume any atavism on the part of the bacteria. The result is entirely in accordance with other work carried out in this Laboratory. It has been shown in various of our papers that the activity of the bacteria of the soil is increased by exposing the soil to conditions unfavourable to active life (e.g. great cold, heat, drought etc.[4]) and then allowing the conditions to become more favourable again. On the other hand the bacterial activity suffers in the long

[1] Löhnis, F. and Sabaschnikoff, *Centr. Bakt. Par.* II. Abt. 1908, **20**, 322—332 and also Löhnis, F., *Vorlesungen über landwirtschaftliche Bakteriologie*, 1913, p. 340.

[2] Müntz, A. and Gaudechon, H., "Le reveil de la Terre," *Compt. Rend.* 1912, **154**, 163—168.

[3] The method was to inoculate soil taken at various dates into soil sterilised at 100° and then to find the amount of nitrification that had taken place. Unfortunately no account was taken of the ammonia produced nor was there any recognition of the special effect of such heated soil in inhibiting the development of the nitrifying organisms.

[4] See Russell and Hutchinson, this *Journal*, 1913, **5**, pp. 167 et seq.

run when the soil is uniformly maintained in favourable conditions[1], it remains at a high level only when unfavourable spells intervene. When soil is partially sterilized the detrimental factor may be completely and permanently thrown out of action and bacterial activity then increases considerably; if the treatment has been insufficiently drastic and the factor is only partially suppressed an increase in activity may still take place, but to a less extent and only temporarily[2].

During the winter months the conditions are unfavourable to the general active life in the soil. We have shown that any unfavourable conditions cause the detrimental factor to suffer more than the bacteria. By spring time we should expect this accumulated differential effect to have become fairly marked so that the bacteria are freer than usual from the detrimental factor. Hence a tendency would be expected for an increase in the rate of nitrate production and (if Löhnis' results are correct) in other bacterial reactions. When later on the detrimental factor recovers, the rate of nitrate production falls off: in the summer therefore a slower rate would be expected, and, as we have seen, it appears to occur.

A similar action would explain the marked rise in the amount of nitrates after the hot dry summer of 1911. The soil became to some extent partially sterilised. This is seen in the clay and the loams; it is not evident in the sand but the moisture content had here run down and remained too low for bacterial action.

Thus these field observations fall into line with our view that two groups of organisms exist in the soil, one engaged in plant food production, and another, which is on the whole detrimental, but is somewhat more affected by adverse conditions.

The next question that needs some discussion is the loss of nitrate during winter. Two reasons are commonly put forward in explanation: denitrification and leaching. In so far as the soil lies waterlogged during winter there is obviously the possibility of the anaerobic conditions necessary for denitrification. The clay and loams investigated were very wet and sticky in winter but not actually waterlogged; the percentage of water in January 1912 was :—

Clay	Loam (Ridgmont)	Loam (Rothamsted)	Sand
29·2	15·5	17·5	9·6

Thus the clay was the wettest, the loams came next, while the sand was driest.

[1] Russell and Golding, this *Journal*, 1912, **5**, 27; Russell and Petherbridge, *ibid.* 1912, **5**, 88.

[2] Russell and Hutchinson, *loc. cit.* p. 168.

On the other hand percolation is most rapid through the sand and the loams and slowest through the clay, in consequence the amount of leaching is smallest in the clay and greatest in the sand.

These properties enable us to discover whether the main winter losses arise from denitrification or leaching; if from the former we should expect to find them most marked on the wet clay and least on the drier sand; if from the latter they would be most marked on the sand and the loam and least on the clay. Reference to Table I shows that the clay does as a matter of fact suffer less loss of nitrate than the sand and the loams; it starts with a lower quantity in the autumn but ends up with more in the spring.

The most serious loss of nitrate in winter thus appears to arise from leaching and not from denitrification.

Further evidence is obtained from the results of the dunged plots at Rothamsted. In midwinter (Feb. 4th, 1913) the amounts of nitrate in Broadbalk field were :—

Parts per million of soil	Dunged plot (Plot 2)	Unmanured (Plot 3)	N. only (Plot 10)	Complete artificials N. P. K. etc. (Plot 7)
0—9″	10	3	3	6
9—18″	7	4	4	6
lbs. per acre, 0—18″ ...	41	20	18	31
Moisture, per cent.				
0—9″	21·2	15·0	16·6	18·7
9—18″	19·3	16·3	16·1	15·7

While in other fields the amounts were :—

Parts per million	Hoosfield barley plots		Little Hoos rotation plots		Barnfield mangold plots	
	Dunged Plot 7²	Complete artificials 4 A	Dunged plot 5 A*	No dung 1 A	Dunged 1—0	No dung 6—0
0—9′	6	3	5	2	10	4
9—18″	6	3	4	4	7	5
lbs. per acre, 0—18″...	27	16	23	14	41	23
Moisture per cent.						
0—9″	26·2	19·1	18·1	17·0	20·6	15·6
9—18″	18·5	16·8	20·9	16·4	21·9	18·9

* On this plot the dung was applied in the previous October (Oct. 23rd, 1912), on Barnfield it was applied in the preceding April and on Hoosfield in Feb. 1911.

The dunged plots were very considerably wetter than the others; the organic matter caused the water to be held up and thus reduced the amount of percolation. They had lain wet for a long time. All the conditions indeed seemed favourable for denitrification; there were notable quantities of organic matter and a considerable accumulation of water. Yet without exception the dunged plots all contain much more nitrate than the drier plots poorer in organic matter and less favourable to denitrification.

In no case was the land actually waterlogged, so that there was always the possibility of the diffusion of air into the soil; the temperature also was low, although it was above the freezing point. These are common conditions on loams and clays in mild winters and we may conclude that the winter losses of nitrate arise rather from leaching than from denitrification.

The effect of the crop on nitrate production. It has been shown on p. 35 that the amount of nitrate accumulated in cropped land at the end of the season is less than that in fallow land even after allowance has been made for the nitrogen absorbed by the crop. The conditions on a cropped soil are therefore less favourable to nitrate accumulation than those on uncropped land. Two different types of factors may be expected to come into play; negative factors, such as lack of moisture or low temperature on the cropped land, or some positive factor such as a possible direct effect of the growing plant on the nitrate (other than absorption) or on the decomposition processes going on in the soil. In all the samples moisture was determined at the same time as the nitrates, so that we have full data on this point. The figures show less difference than might have been expected between the cropped and the fallow plot, the losses due to the transpiration of the crop being somewhat counterbalanced by the protection against evaporation afforded by the shade of the crop. The following data afford illustration:—

1911......	May 17		June 8		Sept. 13	
	Fallow	Cropped	Fallow	Cropped	Fallow	Cropped
0—9″	14·3	14·8	12·2	10·6	6·2	5·1
9—18″	16·6	16·6	13·7	13·4	12·9	—

per cent. of moisture in the soil

1912

April 19		May 13		June 26		July 22		Sept. 26	
Fallow	Cropped	Fallow	Cropped	Fallow	Cropped	Fallow	Cropped	Fallow	Cropped
10·9 12·2	10·8 14·2	12·0 15·3	9·9 12·5	13·0 13·9	13·1 15·4	12·6 13·7	11·7 15·0	11·1 14·9	10·8 15·2

per cent. of moisture in the soil

Laboratory experiments show that nitrification still goes on when the moisture content is 11 per cent.; less than this amount did not commonly occur in the soil.

Temperature readings were not generally taken, but when they were they showed that the cropped land was cooler than the fallow land in hot weather. It is impossible to say how far these differences in temperature and moisture may have reacted on the rate of nitrate production, and whether they are sufficient to account for the whole of the difference observed.

This depressing effect of the crop on the rate of nitrate accumulation has been observed before. Eight years ago Warington[1] showed that the amount of nitrate in the drainage water from Broadbalk field was considerably less than was expected from the manure supplied and the crop reaped. The result is not wholly experimental, for it involves certain assumptions as to the amount of water draining away for which no direct evidence could be obtained; nevertheless as they were drawn up by Sir Henry Gilbert they deserve very serious consideration. Warington thought that denitrification might account for some of the discrepancy but not for all, as it could hardly be supposed to act in dry summer weather: he further suggested that the nitrate might be taken up by the plant and then somehow lost before harvest. More recently Lyon and Bizzell[2] found *more* nitrate on land cropped with maize (after allowing for the nitrogen present in the crop) than on fallow land of similar previous history, and concluded that the growing maize plant in some way stimulated nitrification. During the latter part of the life of the plant less nitrate was found in the cropped than in the fallow land, and the further conclusion is drawn that nitrification is inhibited

[1] *Trans. Highland Agric. Soc.* 1905, **17**, pp. 175 et seq.

[2] Lyon, T. Lyttleton and Bizzell, James A., *Journal of the Franklin Institute*, Jan.—Feb. 1911, "The Relation of certain Non-leguminous Plants to the Nitrate Content of Soils." (All their figures are quoted as NO_3 but for convenience of comparison I have also reduced them to N.)

by the conditions accompanying the decreasing activities of the roots. On the other hand where oats and potatoes were grown the nitrates were never so high in the cropped as in the uncropped land, again, apparently, after allowing for what has been absorbed by the crop. The following amounts of nitrogen as nitrate occurred in parts per million of soils :—

1908	Fallow land		Land carrying maize		1909	Fallow land		Land carrying oats	
	as NO_3	as N.	as NO_3	as N.		as NO_3	as N.	as NO_3	as N.
May 19	21·9	4·9	17·5	3·9	April 22	84·0	19·0	48·1	10·9
June 22	48·1	10·9	41·3	9·3	June 24	55·7	12·6	11·1	2·5
July 6	64·1	14·5	62·8	14·2	July 12	55·8	12·5	4·6	1·0
July 27	186·8	42·1	191·2	43·2	Aug. 7	81·6	18·4	3·7	0·8
Aug. 10	178·6	40·3	165·3	37·3					

It is interesting to observe that the figures are generally of the same order as ours excepting only in July and August 1908.

I have never observed any increase in nitrate on cropped land such as is recorded in the maize experiments of Lyon and Bizzell ; my results with wheat and barley have always shown a decrease, like theirs with oats. Leather's experiments[1] also show a decrease. The nitrate in the drainage water from the fallow gauges at Pusa contained respectively 261·5 and 209·6 lbs. per acre during the period 1907—9, while that in the drainage water and crops of the gauges cropped with grass accounted only for 128·4 and 115·6 lbs. per acre over the same period. The final rainfall before the account was made up was so heavy as to deplete the gauges of nitrate, so that no error arises through the retention of nitrate in the soil.

Dehérain's experiments[2] made at Grignon, near Paris, between 1892 and 1897 also showed much more nitrate coming from the fallow lysimeters than from those covered with crops even after allowing for what was absorbed by the crop. In this case, however, it is uncertain how much nitrate was left in the soil, the rainfall probably being insufficient to wash it all out.

It seems to be an established fact that *less nitrate accumulates, and apparently less nitrate is produced, on cropped land than on fallow land,*

[1] "Records of drainage in India," J. Walter Leather. *Memoirs of the Dept. of Agric. in India*, Chemical Series, 1912, II, 63—140.

[2] *Traité de chimie Agricole*, M. Dehérain, pp. 584—599.

even after allowing for the nitrate absorbed by the crop. This result has been obtained under such widely different climatic conditions as prevail at Rothamsted in England, at Pusa in India, at Ithaca in New York State, and apparently at Grignon near Paris[1]. Although the actual experimental figures refer only to the accumulation of nitrate we are probably justified in supposing that they indicate a diminished *production* of nitrate in cropped land, otherwise we have to assume some destructive process at work in the cropped soil that does not go on in the fallow soil, an assumption for which there is no evidence at all. The wide-range of climatic conditions under which the result is obtained seems to preclude any assumption that the diminished production is due to the effect of the crop on the temperature or moisture content of the soil. There appears to remain only the possibility that the growing plant has a direct effect on the decomposition processes going on in the soil. Unfortunately field experiments alone do not enable us to decide this question; there is, however, sufficient indication of a direct effect to justify a systematic investigation of the problem.

On the Determination of Nitrates in Soils.

The method adopted in the Rothamsted laboratory was originally devised by Warington and consists in extracting the soil with water, reducing the solution with a zinc-copper couple[2] and estimating the ammonia in the usual way. It is both simple and accurate, and has now become part of our regular laboratory routine.

The details are as follows: The soil is brought down as rapidly as can be from the field; it is sampled, lots of 200 grams are weighed, put to dry[3] in a chamber at 38°—40° and weighed again when dry. Then

[1] A similar result seems to have been obtained by B. Welbel in the lysimeter experiments at Ploty, Podolie, Russia. In the French summary of its 11th Report (for 1905) he states:—"Les cultures en vases montrent encore que les plantes fourragères possédent une influence individuelle sur l'énergie des procès de nitrification: ainsi l'influence de l'esparcette est supérieure à celle de la luzerne." Unfortunately the details are given only in the Russian text.

[2] Williams' method, *Trans. Chem. Soc.*, 1881, **39**, 100.

[3] It is not necessary to dry light soils and they can be extracted straight away with water. Heavy soils, however, do not usually allow sufficient percolation to admit of extraction until they have first been dried as directed; our Rothamsted soils, for example, have to be treated in this way as a rule. We are not prepared to say that the drying is without effect on the nitrate content, but we find that it greatly facilitates extraction and it leads to higher and more uniform results than are obtained otherwise. As a precaution, however, all the soils throughout a given investigation are invariably treated alike, and either all dried, or, if they are sufficiently pervious, all extracted in the fresh state.

the soil is roughly pounded in a mortar, put on to a Buchner funnel and extracted with 600—800 c.c. of distilled water. To the extract is added a small quantity of ignited magnesia (about 0·05 gram); it is then concentrated in a Jena glass beaker to about 100 c.c., transferred to an 8 oz. bottle 5½ ins. high to the shoulder and 2 ins. diameter, and acidified with acetic acid. Some care is needed here to see that all the magnesia is dissolved; part may remain unaltered owing to the narrowness of the bottle even though the solution gives at first an acid reaction.

Two pieces of the zinc-copper couple are then added. These are prepared from strips of zinc foil 4 inches long and 2 inches wide bent into half-circles round a cylindrical piece of wood. The strips are immersed for a few minutes in caustic soda solution, then washed under the tap and immersed in dilute sulphuric acid, again washed in water and transferred to a 2 per cent. solution of copper sulphate. In a few seconds a dark coating of copper is deposited; the strip is taken out, at once placed in distilled water for a few seconds and then dropped in to the acidified soil extract. The bottle is now corked and placed in an incubator kept at 25—30°[1] for 2 days. Reduction is by this time complete and the ammonia may be distilled off and estimated by titration, or, in the case of small quantities, by nesslerisation.

The following data show that the method gives satisfactory results. A known quantity of sodium nitrate was added to soil, the total amount of nitrate was then determined; the results show that the amount found corresponds closely with what was expected :—

	N. as nitrate originally present	N. as nitrate added	N. as nitrate expected	N. as nitrate found
Soil A	24 24	11 5	35 29	35 29
Soil B	12	10	22	22

Parts per million of dry soil

It does not appear that the determination is complicated by the presence of other nitrogenous organic substances that might be expected

[1] A worn out steam oven does very well for this; if the space between the walls is filled with water it is not difficult to keep the temperature within proper limits.

in arable soils. Urea, however, is hydrolysed to some extent and causes the results to come out rather too high:—

Compound added to soil	N. in added compound	N. as nitrate originally present in soil	N. as nitrate found	Error caused by added compound
Asparagine	5	17	18	1
,,	7·5	29	29	none
,,	10	12	12	none
,,	15	24	25	1
Betain	5	17	18	1
,,	10	12	13	1
Peptone	5	17	18	1
,,	10	12	13	1
Urea	5	17	19	2
,,	10	12	15	3

Parts per million of dry soil

Urea is so easily decomposed in the soil that it is not likely to give rise to difficulties in practice, while the small error introduced by the other substances is, as we shall see, less than the error of sampling.

Pasture soils and very heavily manured soils often give a dark coloured extract containing nitrogenous compounds of unknown constitution, and in such cases it is probably not safe to regard the figures as representing the nitrates only, but to give some wider designation as has already been done in some of our papers[1].

Various reducing substances appear to affect the determination and the method does not always give reliable results for pot experiment work (e.g. where calcium sulphide has been added to the soil). In experiments of this kind it is necessary to ascertain whether the method holds before embarking in a series of determinations.

The variation in the field. A fair amount of uniformity exists in the nitrate content of a plot which has been uniformly treated and the differences between the various mixed samples do not generally amount to more than about 2 parts per million. Larger differences, however, occur when dung has recently been applied owing to the difficulty of getting a regular distribution. At least three cores have to be taken even on a tolerably uniform plot.

The following results show the kind of variation that is obtained among samples taken from the same plot when single cores only are taken:—

[1] E.g. this *Journal*, 1912, **5**, 27.

Sample	Broadbalk orchard, 1909						Barnfield, April 18, 1913				Harpenden Field, May 14, 1913	
	April 6		July 6		Oct. 28		Unmanured (8—0)		Dunged*			
	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″
1	4	4	6	4	5·5	6	4	4	8	6	7	9·5
2	4	4	7	7	5·5	9	3	4	17	4·5	13	9
3	—	—	—	—	—	—	2·5	2·5	—	7	10	8·5

* Dung applied March 28, 1913.

But when mixtures of three cores are taken the results are more uniform so long as the soil is dried before analysis:—

	Soil dried before analysis				Soil analysed fresh from field			
	Hoos fallow		Hoos dunged plot		Hoos fallow		Hoos dunged plot	
	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″	0—9″	9—18″
1st three cores	7	7	9	6	7	8	6	6
2nd ,, ,,	9	5	10	4	9	3	5	3

Parts per million

	0—18″	0—18″	0—18″	0—18″
1st three cores	37	34	40	28
2nd ,, ,,	37	31	32	18

lbs. per acre

SUMMARY AND CONCLUSIONS.

The amount of nitrate in the soil of arable land fluctuates regularly but in these experiments it rarely exceeded the following values:—

	Per million	Per cent.	lbs. per acre 0—18″
Sand	6	·0006	28
Loam	23	·0023	115

(excepting on heavily dunged land, when it rose to 37 parts per million)

Clay	14	·0014	60

In almost all the soils examined the accumulation of nitrate took place most rapidly in late spring or early summer. After this there was usually little if any gain and very frequently a loss. In the hot dry autumn of 1911, however, the accumulation continued in some of the soils right on till September.

During the winter loss of nitrate takes place. This was more marked in the wet winter of 1911—12 than in the drier winter of 1908—09.

The fluctuations in nitrate content are more marked on loams than on clays or sands. Clays lose less of their nitrates in winter, but on the other hand they accumulate smaller amounts in June and July. Sands lose much of their nitrates in winter and do not accumulate very large amounts in summer. It appears that the main loss in winter is due to leaching and not to denitrification.

On comparing the nitrate content of cropped and fallow land it is found that during late summer and early autumn the fallow land is the richer even after allowing for the nitrate taken up by the crop. Indeed no evidence could be obtained that any nitrate was produced in the soil during the time of active crop growth, although nitrate accumulation was taking place on adjacent fallow land. The question arises whether the growth of a crop exerts any effect on the rate of nitrate production in the soil. The data to hand do not enable us definitely to settle this point.

The rapid rise in nitrate content in spring does not usually set in immediately the warm weather begins; there is a longer or shorter lag. There are indications of greater bacterial activity in early summer than later on, a phenomenon readily explicable on our view that the soil population is complex and includes organisms which are detrimental to the decomposition of bacteria but which are on the whole more readily put out of action.

The supply of nitrate to the plant is known to be a factor of prime importance in plant growth. Similarly it is found that the factors which determine the accumulation of nitrates in the soil also play a great part in determining the amount of crop production. Thus heavy winter rainfall, which washes out nitrates, tends to reduce crop growth: on the other hand hot dry summers succeeded by dry winters are favourable to nitrate accumulation and therefore to crop growth.