

## NITRIFICATION IN SOILS AFTER DIFFERENT PERIODS OF DRYNESS

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It has been shown (Birch <sup>1</sup>) that the longer a soil remains in an air-dry state the greater are the amounts of carbon and nitrogen mineralised on moistening it. These amounts were found to be a significant linear function of the log. of the time the soil was in a dry state prior to moistening. Even short periods in the dry state were sufficient to produce considerably greater amounts of mineral nitrogen, on moistening, than soils that had not been given a preliminary drying. Harpstead and Brage <sup>8</sup> have also reported recently that drying and storage of soils leads to a pronounced increase in their nitrifying ability, a result which they ascribe to changes in the relative numbers of various micro-organisms in the soil.

The experiment from which the foregoing results were quoted is now complete and is described below. It shows the effect of different periods in the dry state on subsequent nitrification in soils with carbon contents ranging from 1 to 7 per cent. The range of soils and drying periods covered are, it is hoped, sufficiently wide for the results to serve as a general guide in soil-nitrogen studies, particularly in countries with pronounced wet and dry seasons. The application of the results is discussed in some detail, particularly with respect to soil nitrogen. Brief reference is also made to carbon rundown in soils.

### EXPERIMENTAL

Each sample was made up by mixing together several samples of about the same carbon content. Thus a number of soils containing about 1 per cent carbon were mixed, and similarly with the others. No attempt was made to

select the soils according to types. The soils had been in an air-dry state in the store for over a year. Table 1 shows some of their characteristics.

TABLE 1

Characteristics of soils				
% C (1)	% C (2)	% N	C/N	pH
6.90	9.18	0.663	13.8	5.48
6.28	8.35	0.693	12.1	6.13
5.48	7.23	0.593	12.3	5.92
4.22	5.61	0.460	12.2	6.22
3.14	4.18	0.330	12.7	6.16
2.06	2.73	0.210	13.0	5.82
1.00	1.33	0.095	14.0	6.05

C(1) Walkley-Black <sup>14</sup> (uncorrected value).

C(2) Walkley-Black value  $\times$  1.33, from which the C/N ratios are derived.

The range of carbon contents was based on the uncorrected Walkley-Black values because the organic material not oxidised by hot chromic acid (for which the correction factor 1.33 is made) is unlikely to be susceptible to microbial decomposition. The uncorrected values should, therefore, be a truer reflection of the material involved in nitrification and decomposition.

Decomposition and nitrification were carried out at approximately field capacity, the optimum moisture condition for such processes (Birch <sup>2</sup>). This was determined for each sample by soaking 20 g with water on a Buchner funnel, removing the excess with suction (using a water pump) and weighing.

To determine the effect of air-drying for different periods on subsequent nitrification the following procedure was adopted. Sufficient of the original air-dry composite sample was taken to give 300 g of soil at field capacity. Five 60-g portions of this moist soil were then put into separate respirometer vessels (8-oz. sample bottles) and left in the respirometer (Birch and Friend <sup>3</sup>) for 14 days. After this period the flush of decomposition, that characteristically follows the moistening of a dry soil, was over. The five portions were then recombined, water was added (if necessary) to bring the weight to 300 g, and the portions were treated as follows:

- (1) 37-g were extracted for the determination of ammonium and nitrate nitrogen (see below), and 5-g were dried at 100°C for moisture content.
- (2) 37-g were returned immediately to the respirometer.
- (3) Five 37-g portions were spread out to dry for 3, 6, 9, 12 and 15 weeks with a few unavoidable exceptions noted in Table 2.
- (4) Five 5-g portions were air dried as for (3).

Measurement (1) gives the amount of mineral nitrogen present at the start of the experiment proper and has to be subtracted from subsequent determinations to determine the effect of drying and no-drying on nitrification.

The 37-g portion returned immediately to the respirometer, treatment (2), was left there for 19 days, after which the amount of carbon mineralised

and the amount of mineral nitrogen present was determined as described below. The amount of nitrogen mineralised during treatment (2) is obtained by subtracting the amount present at the start of the treatment (measurement (1) above) from the amount present at the end of treatment (2). This represents the amount of nitrogen mineralised in a soil without a preliminary drying (since the drying effect following the initial moistening of the soil is eliminated by subtracting measurement (1)). This amount is strictly comparable with the magnitudes of nitrification following the moistening of the samples treated as in (3) which were dried at the same stage that the moist sample was returned to the respirometer (treatment (2)). The amount of carbon mineralised is, in all instances, given directly by the amount of carbon dioxide evolved during the 19-day decomposition period in the respirometer.

The five 37-g portions dried for different periods were treated as follows. After the required period of drying the sample was weighed and water added to bring it to 37-g. The moist sample was then kept in the respirometer for 19 days after which the amount of carbon mineralised and the amount of mineral nitrogen were determined. The latter, minus the amount present prior to incubation (measurement (1)) gives the amount of mineral nitrogen produced following the moistening of a dry soil. To determine the extra amounts of mineral nitrogen produced as a result of drying (followed by moistening) compared with no drying the values in column 4, Table 2, are subtracted from the values in columns 5, 6, 7, 8 or 9.

At the same time that the air-dried samples (treatment (3)) were moistened and put in the respirometer the original 5-g samples (treatment (4)) air-dried for the same period, were dried at 100°C for moisture content. The percentages moisture in the air-dry samples at the time of moistening are shown in Table 2. The carbon and nitrogen mineralisation data in this table are expressed as mg/100 g soil on an oven-dry basis. The moisture figures refer to the amount of water lost from the air-dry soils when kept at 100°C for 24 hours.

#### *Determination of carbon and nitrogen mineralisation*

**Carbon.** After the 19-day decomposition period in the respirometer the caustic soda solution (in which the evolved carbon dioxide had been absorbed) was transferred to a 100-ml volumetric flask and diluted immediately to the mark. A 5-ml aliquot was then titrated with *N*/10 hydrochloric acid using methyl orange (reading *a*). A second 5-ml aliquot was treated with excess 0.4 *N* barium chloride solution and again titrated, but against phenolphthalein (reading *b*).

$$(a - b) \times 22.4 = \text{ml CO}_2 \text{ evolved.}$$

$$(a - b) \times 12 = \text{mg C mineralised.}$$

**Nitrogen.** After the 19-day decomposition period the sample was mechanically shaken for 0.5 h with 50 ml 2*N* potassium chloride solution, 20 ml *N* hydrochloric acid and 30 ml water, and then filtered. A 50-ml



aliquot of the filtrate was then steam distilled after adding 3-g of magnesium oxide. The ammonia liberated was collected in 10 ml of a 2% solution of boric acid containing methyl red-methylene blue indicator, and the amount determined by titration with  $N/70$  hydrochloric acid. Devarda's alloy (2-g) was then added and the distillation repeated for the determination of nitrate nitrogen. The nitrogen mineralisation data therefore refer to both ammonia and nitrate nitrogen mineralised during decomposition, expressed however in units of nitrogen.

### RESULTS

The amounts of carbon mineralised and the amounts of mineral nitrogen present after 19 days in the respirometer following the various treatments are given in Table 2. To obtain the amounts of nitrogen mineralised the mineral-nitrogen data in column 3 have to be subtracted from the other values in columns 4 to 9. The C/N ratios for the mineralisation process are calculated from these data.

Table 3 is a rearrangement of some of the data in Table 2 expressed in units of more practical application. It shows, as pounds of sulphate of ammonia per acre 6" (assuming this to weigh  $2 \times 10^6$  lbs.) the amounts of mineral nitrogen produced during 19 days with no drying and after drying for different periods, followed by 19 days in the moist state. The extra amounts produced by drying, compared with no drying, are also shown in the same units and as a percentage of the no-drying treatments.

Table 3 should be of general application since it has been shown (Birch <sup>2</sup>) that the magnitude of decomposition on moistening a dry soil is largely a function, for a given drying period, of the carbon content of the soil and is little affected by the soil type with which the humus is associated, with the exception of peat soils and related soils.

The extra nitrogen and carbon mineralised after drying compared with no-drying, in relation to the period the soils were dry prior to moistening, is best expressed by a logarithmic relationship. The equations for each soil are given in Table 4, in which  $Y_n$  and  $Y_c$  are respectively the extra amounts of nitrogen and carbon mineralised (mg/100 g soil. Table 2, cols. 5, 6, 7, 8 or 9 minus col. 4) and  $X = \log.$  of the number of weeks the soil was air dried prior to moistening.

TABLE 3

Nitrogen mineralisation data as pounds sulphate of ammonia per acre 6", following the various treatments. See Table 2 for exceptions in the length of the drying periods							
% C in Soil	During 19 days moist	Weeks air-dried prior to moistening					
		0	3	6	9	12	15
6.90	Amount mineralised. . . .	186	1,506	2,217	2,541	2,817	2,995
	Incr. over no drying. . . .		1,320	2,031	2,355	2,631	2,809
	% " " " " . . . .		810	1,192	1,366	1,514	1,610
6.28	Amount mineralised. . . .	405	1,173	1,241	1,674	1,735	1,974
	Incr. over no drying. . . .		768	836	1,269	1,330	1,569
	% " " " " . . . .		290	306	413	428	487
5.48	Amount mineralised. . . .	464	1,058	1,232	1,205	1,504	1,574
	Incr. over no drying. . . .		594	768	741	1,040	1,110
	% " " " " . . . .		228	266	260	324	330
4.22	Amount mineralised. . . .	466	886	915	1,056	1,235	1,159
	Incr. over no drying. . . .		420	449	590	769	693
	% " " " " . . . .		190	196	227	265	249
3.14	Amount mineralised. . . .	318	503	692	821	880	821
	Incr. over no drying. . . .		185	374	503	562	503
	% " " " " . . . .		158	218	258	277	258
2.06	Amount mineralised. . . .	139	439	486	627	706	911
	Incr. over no drying. . . .		300	347	488	567	772
	% " " " " . . . .		316	350	451	508	655
1.00	Amount mineralised. . . .	174	317	285	515	406	484
	Incr. over no drying. . . .		143	111	341	232	310
	% " " " " . . . .		182	164	296	233	278

TABLE 4

Relationship between extra nitrogen and carbon mineralised and period the soils were dry prior to moistening		
Soil	Extra N mineralised	Extra C mineralised
6.90% C	$Y_n = 20.2X + 4.2$ ( $r^2 = 0.997$ )	$Y_c = 90.9X - 8.7$ ( $r^2 = 0.998$ )
6.28% C	$Y_n = 11.2X + 1.5$ ( $r^2 = 0.901$ )	$Y_c = 32.1X + 5.7$ ( $r^2 = 0.889$ )
5.48% C	$Y_n = 6.8X + 2.3$ ( $r^2 = 0.775$ )	$Y_c = 33.2X + 2.1$ ( $r^2 = 0.956$ )
4.22% C	$Y_n = 4.8X + 1.2$ ( $r^2 = 0.786$ )	$Y_c = 43.7X - 19.6$ ( $r^2 = 0.947$ )
3.14% C	$Y_n = 5.2X - 0.40$ ( $r^2 = 0.899$ )	$Y_c = 35.0X - 14.3$ ( $r^2 = 0.976$ )
2.06% C	$Y_n = 6.2X - 0.59$ ( $r^2 = 0.837$ )	—
1.00% C	$Y_n = 2.6X - 0.07$ ( $r^2 = 0.526$ )	$Y_c = 11.4X - 2.54$ ( $r^2 = 0.743$ )

The equations are of the form  $y = ax + b$ . Since  $\log 1 = 0$ , the  $b$  values in the above equations show the extra amounts of

nitrogen mineralised after 1 week's air-drying. Further, from the equations, no extra nitrogen is mineralised until the soils have been exposed to the drying process for longer than 0.62, 0.73, 0.46, 0.56, 1.20, 1.25, and 1.06 weeks for the 6.9 to 1.0% C soils respectively. Presumably these are the periods required for the moist soils to reach the air-dry state at which the drying effect first starts to manifest itself. Clearly the equations cannot hold for very long periods, but for the lengths of dry periods found in agriculture they are applicable.

#### DISCUSSION

The following discussion deals (a) with the results themselves, (b) with the application of these results, and (c) with the material and mechanism possibly involved.

##### (a) *The results*

Table 3 shows that for a given drying period the amounts of mineral nitrogen produced on moistening are directly related to the carbon contents of the soils with, however, outstandingly high values for the 6.90% C soil. Carbon mineralisation is also generally proportional to the carbon content of the soil (see Table 2), as already noted for other soils (Birch<sup>2</sup>). The relationships between carbon content of the soil and carbon or nitrogen mineralisation is less well defined for the non-dried soils (Table 2, col. 4; Table 3, col. 3). Possibly non-humified material is also present which decomposes not only during the flush of decomposition of the rather nitrogen-rich humus but also afterwards, leading to the uptake of some mineral nitrogen by the micro-organisms. Such behaviour could apply to both the 6.90 and 2.06% C soils (Table 3). Consequently, since the magnitudes of the drying effect as a percentage of no-drying are partly a function of the values given in Table 3, Col. 3., large values are obtained with these two soils.

Soil drying enhances the magnitudes both of carbon and nitrogen mineralisation (Tables 2 to 4). The C/N ratios for the mineralisation processes after drying and moistening (Table 2, cols. 5 to 9) are, however less than after no drying (Table 2, col. 4). Hence it appears that the rate of nitrogen mineralisation after moistening the soil falls off more rapidly than that of carbon mineralisation. It has been

shown (Birch<sup>1</sup>) that following the moistening of a dry soil two decomposition processes occur namely (1) decomposition of soluble organic material without nitrification and (2) decomposition at the organic surface with nitrification, the rates of both processes rapidly declining. Presumably drying has a more transient effect on (2) than (1) leading to an increase in the C/N ratios for the mineralisation process as decomposition continues. Prolonged decomposition of organic residues not affected by the drying *i.e.* non-humic material, would further enhance this effect particularly if this also involved utilisation by the micro-organisms of mineral nitrogen produced earlier during the flush of decomposition.

The C/N ratios for the carbon and nitrogen mineralised after drying and moistening are quite low. The true values are probably even lower with reference to the actual material mineralised for, as mentioned above, part of the carbon mineralised is derived from soluble organic material that produces no mineral nitrogen during decomposition. Hence it appears that the material involved in nitrification is very nitrogenous.

From Table 3 it is seen that the magnitude of the drying effect on nitrogen mineralisation is considerable. Thus, with the 6.9% C soil drying for 9 weeks or more leads to the production of extra nitrogen on moistening (compared with no drying) equivalent to over a ton of sulphate of ammonia per acre 6''. Even after 3 weeks drying (a condition likely to obtain in temperate countries) considerable extra amounts are produced, while after 9 weeks drying, a state frequently achieved under tropical conditions, the extra amount produced even for the least organic soil was 341 lb. The magnitude of these effects for a given soil dried for a given period will gradually diminish with each successive drying and rewetting as the supply of material involved is depleted.

(b) *Application of the results*

It should be borne in mind that the flush of decomposition and nitrogen mineralisation that follows the moistening of a dry soil is repetitive with successive drying and rewetting treatments. This pattern of behaviour and the possible mechanism underlying it (see Birch<sup>1</sup>), which is discussed briefly later, can be usefully applied to several soil problems. Table 3 shows the magnitude of the drying effect and Table 4 indicates that it conforms more or



less to a basic principle. The effect of drying therefore follows a predictable course. Some of the applications of the drying effect have already been mentioned (Birch <sup>2</sup>), but not in the light of the magnitudes of the effects involved. This is now possible following the quantitative studies described in the experimental section.

(1) Nitrogen-fertiliser trials. In view of the large amounts of mineral nitrogen produced on moistening a dry soil, the results of such trials will have to be considered in relation (a) to the time of laying down the trial *i.e.* whether this was in time to catch the flush of nitrate production at the start of the rains or not, and (b) in relation to the length of the dry period prior to the rains.

With regard to (a), if planting is carried out once the flush of nitrification is over the crop will depend on the slow rate of nitrification that then occurs (Birch <sup>2</sup>, and Table 3, col. 3), if the nitrate produced during the flush is leached out. With the more humic soils nitrate production under continued moist conditions may suffice for the crop. With less humic soils, however, the rate of supply under these conditions may be inadequate, in which case the time of planting may have a critical effect on the results.

With regard to (b), if the trials are laid down at the start of the rains, the length of the dry period prior to these will be important particularly for the less humic soils as shown in Table 3.

(2) Yield-rainfall relationships. These usually ignore the length of the dry season in relation to rainfall, though this, as shown above, is important with regard to its effect on the subsequent magnitude of nitrification. Yields under adequate rainfall but after different periods of dryness may be very different. An interesting example is reported by Laycock <sup>10</sup>. He found a depressing effect on tea yield of dry-season rain. The effect of rain during a normally dry period will be to shorten the length of the dry period prior to the main rains when growth occurs. Hence the dry-season rains will tend to reduce the amount of mineral nitrogen then produced, with a concomitant effect on yield. Laycock <sup>10</sup> also found that the increment in crop per inch of rain during the early period of the rains was twice that during the later period. A result which could be due, partly at least, to the flush of nitrate production that follows the moistening of a dry soil. A dry spell

during the rains should also lead to a flush of nitrate production when these are resumed. Wood <sup>15</sup> (private communication) has reported that a dry spell during the growth of tobacco in Nyasaland was followed, when rain again occurred, by the uptake of large amounts of nitrogen by the leaf with adverse effects on its quality. This again demonstrates the important effect of drying on subsequent nitrate production.

Dry season rains will, however, only be detrimental to crops planted later at the start of the main rains if the nitrate produced during the dry season rain is lost through leaching.

(3) Irrigation. Table 3 shows that even a short period in the dry state is sufficient to produce considerable amounts of extra nitrogen on moistening the soil. Where irrigation is practised a short period of surface soil drying should be possible without damage to the crop since this obtains moisture from the subsoil. Remoistening should then have an effect equivalent to a nitrogen application. A period of drying should, if possible, also be introduced between the end of the rains and the start of irrigation, otherwise nitrification will continue at the low rate characteristic of constant moist conditions. In fact Laycock's observation reported above on crop yields in relation to early and late rain can be directly applied to irrigation practices. For any irrigation scheme it would seem advisable to establish a relationship between degrees and periods of drying, and the amounts of nitrogen subsequently mineralised on moistening as described earlier in this paper.

(4) Rundown of soil fertility. This, for nitrogen is a spasmodic process with little loss during the dry season, rapid mineralisation (possibly with leaching) at the start of the rains and a relatively slow rate of mineralisation as these continue. As the soil gradually becomes exhausted of the organic fraction from which the mineral nitrogen is derived a stage will be reached when the amount of mineral nitrogen produced after a short period of drying will be inadequate for crop needs while that produced after a longer period will still be adequate (see Table 3 for possible examples). Hence in countries with two pronounced wet and dry seasons, as in certain parts of Kenya, nitrogen deficiency will first be apparent after the shorter of the two dry periods. Glover and

Birch <sup>4</sup> have reported that a decline in soil fertility (as shown by declining maize yields over successive years) is beginning to show up in crops planted in the short rains (which are preceded by a short dry season) but not yet in crops planted in the long rains (which are preceded by a longer dry period), due account being taken of the differences in the amounts of rainfall.

(5) Effect of shade. The magnitude of nitrification following the moistening of a dry soil is a function not only of the period that the soil was dry prior to moistening but also of the temperature to which the soil was subjected (Birch <sup>1 2</sup>). Higher temperatures appear to accelerate the changes, induced by drying, responsible for the subsequent enhanced nitrification. Unpublished studies here have shown that the drying effect is somewhat enhanced at a temperature of 40°C and considerably enhanced at 60°C, the effect being almost equivalent to heating at 100°C. Since surface soils in the tropics may reach temperatures of 50 to 55°C the effect of shade in inhibiting the subsequent flush of decomposition on moistening should be considerable. Shade should also shorten the period, by delaying drying out, during which the soil is in the dry state. Hence shade should be conservative of organic matter and nitrogen, and it is interesting to note that Ap Griffith <sup>5</sup> found that shade considerably reduced the flush of nitrate when the soil was moistened.

(6) The available-nitrogen status of soils. From Table 3 it appears that any soil with 3 per cent C (approx. 6 per cent organic matter) or more should furnish adequate amounts of mineral nitrogen both from the initial flush of production on moistening (cols. 4 to 8) and from the slower rates of mineralisation that follow this (col. 3). These values refer to the amounts of nitrogen mineralised during 19 days. Soils with less than 3 per cent C produce comparatively little mineral nitrogen once the flush is over (see Table 3). Adequate amounts may or may not be produced during the flush of decomposition depending on the length of the dry period and the temperature reached. These soils appear then to be supplying considerably less mineral nitrogen once the flush is over, and as this stage of nitrification coincides with increased demands by the growing crop, nitrogen deficiencies may

occur. Another factor to be considered is that low-carbon soils are often of a sandy nature which means that nitrogen losses through leaching are likely to be considerable. With soils above 6 to 7 per cent C deviations in the behaviour described above are likely to occur as one moves from humic material of relatively low C/N ratio to undecomposed organic residues whose nitrogen content is such that decomposition to the humic state may be attended by uptake of mineral nitrogen by the micro-organisms. The general relationships described are therefore likely to be valid with soils containing up to 7 per cent C (Walkely-Black, uncorrected) but not above this level.

(7) **Rundown of soil carbon.** The amounts of carbon mineralised after drying and rewetting are shown in Tables 2 and 4. The magnitudes of these losses can best be appreciated when converted to other units. Thus the increased loss of about 20 mg C/100 g soil for the 6.28 and 5.48% C soils dried for 3 weeks is equivalent to 400 pounds C/acre 6". To replace this about 3 tons of fresh organic matter would be required assuming that it contains 50 per cent water and 25 per cent C and that 75 per cent of the carbon is lost as carbon dioxide during its decomposition.

Following the decomposition of organic material (*e.g.* leaf or gelatine) added to the soil it has been found that the succeeding flushes of decomposition on drying and rewetting are bigger and more easily induced than prior to the decomposition of the added material. Hence the material involved in the drying effect appears to be a product of the decomposition of organic matter. Since this material is also decomposable it is difficult to build up organic matter in the soil. However, since its decomposition is controlled by the wetting and drying cycle its decomposition is spread over a number of seasons, which helps to explain the residual effects of added organic matter.

The flush of decomposition following each successive oven-drying and rewetting of a soil (Birch <sup>2</sup>, Expt. 2) still occurs after 105 such treatments though the magnitude is now small. Each successive flush of decomposition decreases according to the equation:

$$Y_c = 35.9 - 15 \log T \quad (r^2 = 0.872, 103 \text{ observations})$$

where  $Y_c$  = mg C mineralised during 5 days after moistening the soil (35 g) and  $T$  = the number of treatments.  $Y_c = 0$  when  $\log T = 2.393$ , *i.e.* the flush of decomposition should no longer occur after about the 250th oven-drying and rewetting. It is estimated that about 73 per cent of the organic carbon originally present in the soil will then have been mineralised, leaving 27 per cent as microbially undecomposable material.

This experiment demonstrates the persistence of the decomposable organic fraction in the soil. Admittedly the soil had initially a high carbon and nitrogen content, but during these successive decompositions no additions were made to the soil (such as would occur under field conditions and the carbon dioxide evolved was adsorbed by sodium hydroxide solution and was therefore not available for synthesis of organic compounds by the micro-organisms.

Under the milder conditions of drying in the field the organic fraction might be expected to persist over a greater number of dryings and rewettings. Since the number of these will be a function of time the rundown of soil carbon under bare fallow and in countries with well-defined wet and dry seasons should, in the light of the foregoing equation, be a function of the log. of the time.

(c) *The material and mechanism involved*

As mentioned in the previous paragraph the material involved in the drying effect is the product of the decomposition of organic matter. The material could be microbial remains accumulated over a long period. The low C/N ratios for the mineralisation process (Birch <sup>1</sup>) indicate that it is very nitrogenous. Soil organic matter is chiefly colloidal and is more or less characterised by two fractions (a) a labile or nutritive fraction and (b) a residual fraction resistant to microbial action. It is evident therefore that only part of the humus is likely to be involved in the drying effect.

It seems probable then that the material involved is a nitrogenous colloid which, in the dry state is in the gel form (Haines <sup>6</sup>). With regard to the effect of ageing and drying Lykov <sup>11</sup> refers to gels that become porous on drying, while Vold *et al.* <sup>13</sup> found that as gels age the mesh structure disintegrates and the constituent particles agglomerate into coarse aggregates. A simple observation here showed that when a jelly made out of gelatine dried out in

a beaker a stage was reached when it split into flakes which broke away from the bottom of the beaker and curled up thereby practically doubling the surface area exposed. It is possible that similar behaviour occurs in the soil where organic colloids are present as thin layers. This observation demonstrates that drying could increase the surface area, and the effect would be of considerable magnitude where large surface areas, as in soils, are involved. An alternative possibility is that the porosity of the gels is increased by drying, as mentioned above and discussed in more detail elsewhere (Birch<sup>1</sup>). Either change would lead to increased surface area. The hypothesis previously advanced (Birch<sup>1</sup>) to explain the drying effect appears therefore to be feasible. This postulates that, on drying, the surface area of the organic gel is increased. On moistening it decreases, the process being reversible, as long as the gel persists in the soil. Immediately on moistening a dry soil a greater surface area is exposed to both solution and decomposition processes than later on after moistening when the reversible process has taken place. It has been shown (Birch<sup>1</sup>) that the organic material that goes into solution on moistening a soil decomposes rapidly, but without nitrification. The enhanced nitrification that also occurs when a soil is moistened must, therefore, involve decomposition, accompanied by nitrification at the gel surface, the rate of nitrification declining as the surface area decreases under moist conditions. In connection with surface decomposition of gels Khudyakov<sup>9</sup> reports that there are bacteria that are capable of breaking down organic-mineral gels, while Rosen and Sajewa<sup>12</sup> state that various organisms can penetrate agar and gelatine by virtue of a force similar to diffusion. Similar behaviour may occur in soils and the persistence of the nitrogenous organic fraction in spite of its inherent decomposibility (as shown by the rapid decomposition that occurs for a short period after each successive drying and rewetting) may be due to the fact that only for a short period after a dry soil is moistened is a relatively large area exposed to decomposition and nitrification processes.

In addition to the effect of drying mentioned above there is also the probability that enhanced nitrification on moistening also occurs (a) as a result of the high microbial activity associated with a freshly developing population and (b) as a result of the decom-

position of dead micro-organisms, killed during the preceding drying. Whatever the factor or factors involved it is evident that soil drying leads to the production of surprisingly large amounts of mineral nitrogen on moistening. Since the amount produced is a function of the humus content of the soil and the log. of the period the soil is in a dry state prior to moistening and since, after moistening, the decline in the rate of nitrification conforms approximately to a first-order reaction (Birch<sup>1</sup>. Calculation subsequently derived from Expt. 8) it is evident that nitrification in soils follows a more or less predictable course since it conforms to certain basic principles. The temperature effect remains to be studied and this could be important under tropical conditions where high surface temperatures are reached. Possibly the magnitudes of the drying effect determined under laboratory conditions (at about 25°C) give an under-estimate of the effect likely to obtain in the field. Hagenzieker<sup>7</sup> however found a topsoil flush of mineral nitrogen in a grey sand equivalent to 224 lb. sulphate of ammonia per acre and this seems to tally with the data for the low-humic soils in Table 3.

#### SUMMARY

An experiment is described in which soils with carbon contents ranging from about 1 to 7 per cent (Walkely-Black, uncorrected) were air dried for 3, 6, 9, 12, and 15 weeks and then remoistened. The amounts of carbon mineralised and ammonia and nitrate-nitrogen subsequently produced during 19 days were then determined and compared with the amounts mineralised from a non-dried soil. For a given drying period the amounts of carbon and nitrogen mineralised were proportional to the carbon content of the soil while, for a given soil, they were found to be a significant linear function of the log of the time the soil was in an air-dry state prior to moistening. With high-humic soils drying produced extra nitrogen on moistening sometimes equivalent to over 1 ton of sulphate of ammonia per acre. Even with low-humic soils values of about 300 pounds were common.

The results of the drying effect are tabulated both in conventional units and as pounds of sulphate of ammonia per acre 6". In the latter units the table should more readily serve as a general guide in applying the results. The application of the results to nitrogen fertiliser trials, irrigation, rundown of soil fertility and soil carbon, the effect of shade *etc.* is then discussed. The material and mechanism possibly involved is also considered. The results should be of fairly wide application since a basic principle operating on material (humus) of more or less uniform composition and common to all soils is involved.

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