MINERALISATION STUDIES ON VIRGIN AND CULTIVATED SUGAR BELT SOILS

by R. A. WOOD

Introduction

The property of virgin soils when first brought into cultivation, of decomposing rapidly with the release of large quantities of mineral nitrogen, is well known, and has been reported by various workers.[4, 5, 7, 9, 10] Initially, on certain soils, the rate of nitrogen mineralisation may be so high that for some time no profitable response is obtained from the use of fertilizer nitrogen. Simultaneously the carbon in the soil organic matter also undergoes rapid decomposition, resulting in large scale mineralisation. Under cultivation this accelerated breakdown apparently continues until all easily decomposed materials have disappeared, those remaining being more resistant. At this stage a reduced rate of mineralisation will occur.

As the South African Sugar Belt contains a remarkable collection of heterogeneous soil groups, it was felt that an examination of some of these before and after cane cultivation would be of considerable interest, particularly with regard to differences in mineralisation rates.

Materials and Methods

Pairs of composite field samples representing 13 different soil groups were taken from a depth of 0—6 inches under third ratoon cane, and closely adjacent bush or grass fallow. After air drying in the laboratory they were crushed and passed through a 2 mm. sieve to remove any gravel or large roots, after which they were stored in bottles. Analyses for the pairs of soils at the beginning of the investigations are given in Table 1.

TABLE I

Analytical Data — Virgin and Cultivated Soils

Soil Group		Series	% Texture				Textural Group	pH	Ca p.p.m.	% org. C	% N	C/N ratio
			C.S.	F.S.	S	C						
Middle Ecca	(V)	Windermere	14	36	16	33	Sandy-clay loam	6.05	710	3.86	0.25	15.4
	(C)							5.20	380	2.11	0.12	17.6
Lower Ecca	(V)	Milkwood	11	17	25	44	Clay loam-clay	6.10	1500	4.10	0.30	13.7
	(C)							5.80	970	3.78	0.16	23.6
T.M.S. (ord.)	(V)	Cartref	56	30	5	7	Sandy-loamy sand	5.20	120	1.15	0.06	19.2
	(C)							4.85	110	1.07	0.05	21.4
T.M.S. (Mist belt)	(V)	Inanda	20	26	13	42	Sandy clay	5.90	480	7.24	0.26	27.8
	(C)							5.10	220	5.94	0.15	39.6
Recent Sand-red	(V)	Lytton	25	60	5	10	Loamy sand	5.75	330	1.00	0.09	11.1
	(C)							4.80	130	0.96	0.05	19.2
Recent Sand-grey	(V)	Fernwood	47	41	5	4	Sand	5.60	260	1.44	0.08	18.0
	(C)							5.50	130	0.93	0.04	23.3
Black dolerite	(V)	Rydalvale	4	9	17	69	Clay	6.20	2400	6.52	0.31	21.0
	(C)							5.90	2400	5.53	0.26	21.3
Red dolerite	(V)	Shortlands	9	18	11	60	Clay	6.40	1900	4.42	0.20	22.1
	(C)							5.45	1040	3.63	0.16	22.7
Granite	(V)	Glenrosa	44	26	10	19	Sandy loam	5.95	460	2.99	0.12	24.9
	(C)							5.10	100	2.27	0.10	22.7
Alluvium	(V)	—	13	10	24	54	Clay	5.60	1040	3.02	0.20	15.1
	(C)							5.50	980	3.11	0.18	17.3
Dwyka tillite	(V)	Williamson	15	40	14	32	Sandy clay loam	6.60	1200	2.75	0.16	17.2
	(C)							5.40	480	2.07	0.12	17.3
Beaufort sand	(V)	Confluence	14	59	7	20	Sandy loam–Sandy clay loam	6.75	820	1.11	0.08	13.9
	(C)							6.15	550	1.32	0.08	16.5
Tugela schist	(V)	Logoza	17	23	10	49	Clay	6.10	760	2.63	0.15	17.5
	(C)							5.80	1040	2.82	0.14	20.1

V = Virgin; C = Cultivated; C.S. = Coarse Sand; F.S. = Fine Sand; S = Silt; C = Clay.

The principal aspects of C and N mineralisation studied were:

(1) the relative amounts of C and mineral N (NH_4 + NO_3) released by the virgin and cultivated soils during incubation.

(2) patterns of C and N decomposition with time.

(3) relative immobilisation effects due to added carbon.

For the majority of this work the modified respirometer technique developed by Birch[3] was employed. This enables the simultaneous study of C and N mineralisation. The soil is incubated in a closed container (respirometer vessel) placed in a constant temperature water bath. The CO_2 evolved from C mineralisation is absorbed in 2N NaOH thus creating a partial vacuum. This causes 2N H_2SO_4 in a side tube connected to the container to rise until contact is made with a platinum electrode (anode), whereupon O_2 is evolved by electrolysis until the pressure is equalised once more. The H_2 evolved at the cathode is collected in a gas burette thus enabling O_2 consumption to be measured, which in turn can be related to CO_2 output. The process is continuous and readings may be taken at any desired interval. Diluting the 2N NaOH to a fixed volume, treating an aliquot with excess 0.4N $BaCl_2$ and titrating with 0.1N HCl using phenolphthalein as indicator, enables the milligrams of C mineralised to be determined.

At this stage the soil may be extracted to determine the amount of N mineralised over the same period. Throughout these investigations mineral N was determined by Nesslerisation according to Saunder's[9] procedure, the results being expressed as parts per million (p.p.m.) on an oven dry basis. In some cases these have been converted to lb. sulphate of ammonia equivalent per acre six inches (2 million pounds soil).

In (1), 50g. air dry samples of 10 groups of virgin and cultivated soils, were moistened to 60 per cent water holding capacity and placed in the respirometer at 35°C for 14 days. At the end of this period the amount of C and N mineralised was determined for each soil as already described.

For (2), 10g. air dry samples of four groups of virgin and cultivated soils were moistened as in (1) and placed in an incubator at 35°C. After periods of 1, 2, 3, 4, 7, 10 and 14 days, duplicate samples of each group were removed and extracted to obtain the pattern of N mineralised with time. A similar pattern for C mineralised had already been obtained in (1) for the comparable soil groups by conversion of the daily measurements of CO_2 evolved.

Finally in (3), 30g. air dry samples of six groups of the soil pairs, were moistened as above, either with or without the addition of 400 p.p.m. C added as glucose. The samples were placed in the respirometer for 6 days at 30°C after which they were removed and the amounts of C mineralised and mineral N present were determined.

Results

Amounts of C and N mineralised

The data presented in Table II show clearly the enhanced decomposition of C and N occurring in the virgin soils when compared with those that are cultivated. As previously demonstrated[12] the capacity to mineralise N varies with the soil group, being broadly related to organic carbon content, but whereas for the cultivated soils this ranges from 230-630 lb. sulphate of ammonia equivalent over two weeks, for the virgin soils over the same period the range is 370-1610 lb., thus explaining the lack of response often obtained when N fertilizers are applied to these soils. C mineralisation is also seen to follow a similar pattern.

TABLE II

C and N Mineralised after two week Incubation Period
(Cultivated and Virgin Soils)

Soil Group	Cultivated				Virgin			
	% org. C	mg. C	mg. N mineralised	N min. as S/A equiv. lb./acre	% org. C	mg. C	mg. N mineralised	N min. as S/A equiv. lb./acre
T.M.S. (ord.)	1.07	21.0	2 3	230	1.15	50 0	3.7	370
Recent Sand-grey	0.93	24.5	2.5	250	1.44	49.5	8.1	810
Middle Ecca	2.11	52.0	3.3	330	3.86	128.5	14.6	1460
Dwyka tillite	2.07	43.0	3.4	340	2.75	65.5	5.4	540
T.M.S. (Mist belt)	5.94	40.0	3.5	350	7.24	112.0	13.8	1380
Lower Ecca	3.78	46.5	3.7	370	4.10	183.0	16 1	1610
Recent Sand-red	0.96	37.5	4.8	480	1.00	41.5	5 2	520
Granite	2.27	41.5	5.0	500	2.99	70.0	7.8	780
Tugela schist	2.82	53.0	5.7	570	2.63	61 0	6.5	650
Red dolerite	3.63	53.0	6.3	630	4.42	72.0	7.7	770

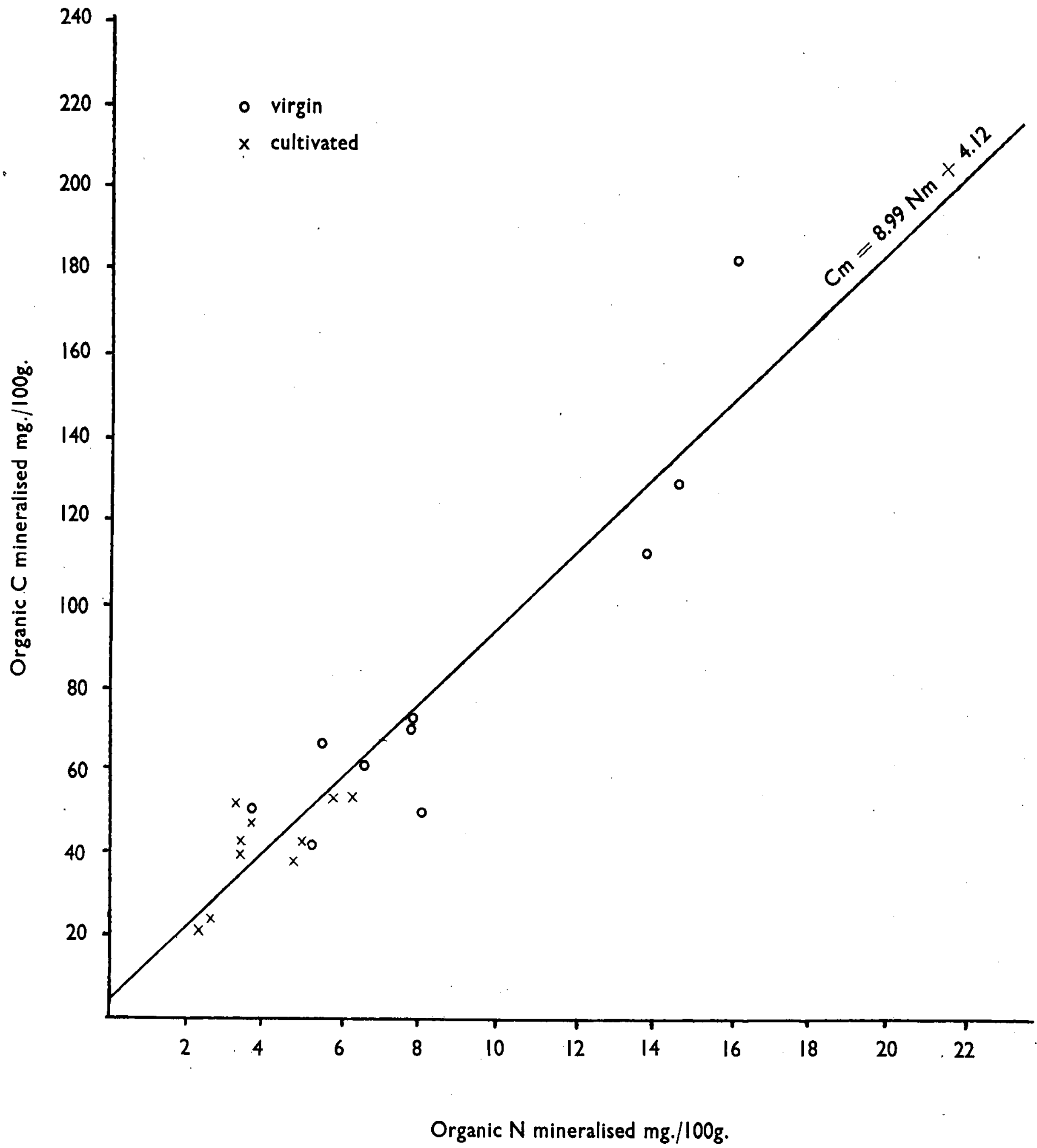

FIGURE 1 : Regression of carbon mineralised on nitrogen mineralised during two week incubation.

Further examination of the data reveals that a highly significant correlation (r=0.937) exists between the amounts of C and N mineralised in both types of soils. The regression of C mineralised on N mineralised is shown in Figure I. The average ratio of C mineralised to N mineralised was 9.6 in the virgin soils and 10.5 in the cultivated soils.

Patterns of Decomposition with Time

The patterns of decomposition occurring during a 14-day period of C and N mineralisation are shown graphically in Figures 2 and 3 for four groups of virgin and cultivated soils. The marked flush of mineralisation following the re-moistening of air dry soils (Birch effect) is well illustrated in both virgin and cultivated soils, though being much more pronounced in the former. Both C and N mineralisation fall off rapidly after the second day as the soluble substrate becomes exhausted, and follow a similar course, decomposition reaching a slow but steady rate after approximately a week, the level being somewhat higher in the virgin soils as might be expected.

Birch [1 2] maintains that two simultaneous but independent decomposition processes occur following the moistening of a dry soil, namely (*a*) decomposition of soluble organic material without N mineralisation and (*b*) decomposition of non-soluble organic material with N mineralisation. He shows that the rate of C mineralisation declines rapidly after the first day and N mineralisation only after the second day of incubation. Our observations are somewhat different as may be seen from Table III. From this data it is apparent that in the virgin soils both C and N mineralisation fall off markedly after the first day while in the cultivated soils C and N mineralisation rates were fairly constant for the first two days declining thereafter. This paralleling of behaviour suggests that perhaps after all the two processes are not entirely independent.

TABLE III

Rate of C and N Mineralisation — First Two Days after Incubation
(Virgin and Cultivated Soils)

Soil Group	VIRGIN				CULTIVATED			
	mg. C Mineralised		p.p.m. N Mineralised		mg. C Mineralised		p.p.m. N Mineralised	
	1st Day	2nd Day	1st Day	2nd Day	1st Day	2nd Day	1st Day	2nd Day
Middle Ecca	37.1	18.7	81.8	35.9	9.0	8.5	6.2	13.5
T.M.S. (Mist belt)	23.2	19.7	40.0	37.0	6.4	6.8	12.0	13.0
Granite	17.9	11.4	25.9	18.6	9.1	8.5	10.8	14.2
Recent Sand-grey	14.5	8.3	30.4	15.1	4.6	4.6	5.2	8.8

Immobilisation Effects

The information presented in Table IV indicates that immobilisation effects due to additional residues high in carbon, are likely to be much more severe in the cultivated than in the virgin soils, but that sufficient nitrogen is released in all soils in the normal way, to exceed appreciably any immobilisation that may occur. The effect of adding glucose is to enhance C mineralisation by increasing the soluble substrate, causing assimilation of some of the soil nitrogen supply by the microbial population.

TABLE IV

Immobilisation Effects due to Addition of Carbon
(After 6 days in respirometer at 30 °C)

Soil Group	CULTIVATED				VIRGIN			
	Nil		400 p.p.m. C		Nil		400 p.p.m. C	
	mg. C min.	Total min. N p.p.m.	mg. C min.	Total min. N p.p.m.	mg. C min.	Total min. N p.p.m.	mg. C min.	Total min. N p.p.m.
T.M.S. (ord.)	12.9	22.5	35.0	2.5	26.5	29.5	54.2	9.5
Recent Sand-grey	14.5	32.5	38.2	14.0	28.2	59.0	61.7	39.0
Middle Ecca	28.1	37.5	53.8	26.0	68.6	118.0	98.5	102.0
T.M.S. (Mist belt)	22.8	59.0	49.3	29.0	69.4	120.0	96.7	101.0
Granite	24.4	55.0	51.6	35.0	35.8	60.0	68.7	47.0
Black dolerite	46.4	77.0	69.8	49.0	67.0	97.0	91.0	69.0

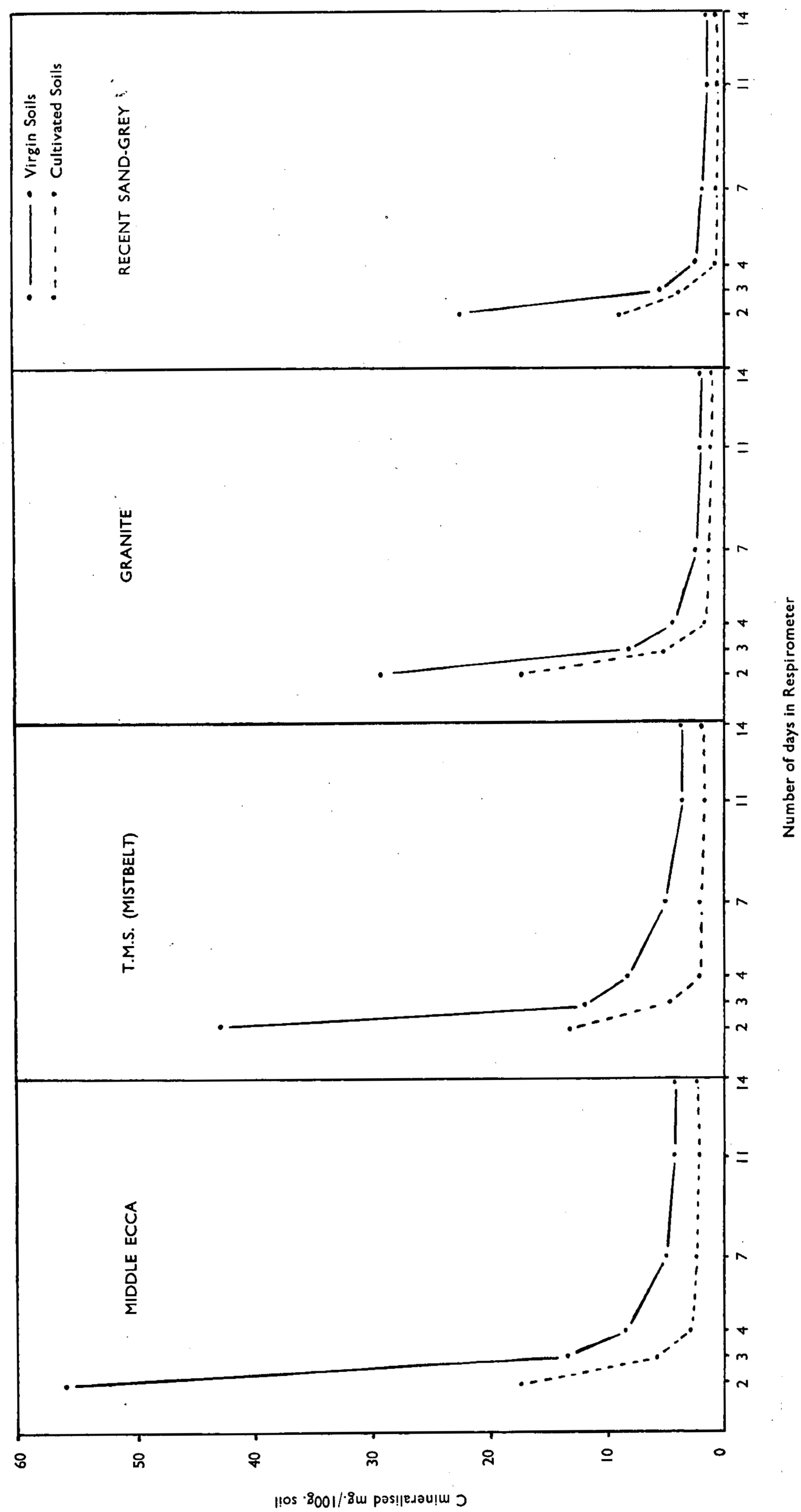

FIGURE 2 : Pattern of carbon mineralisation with time.

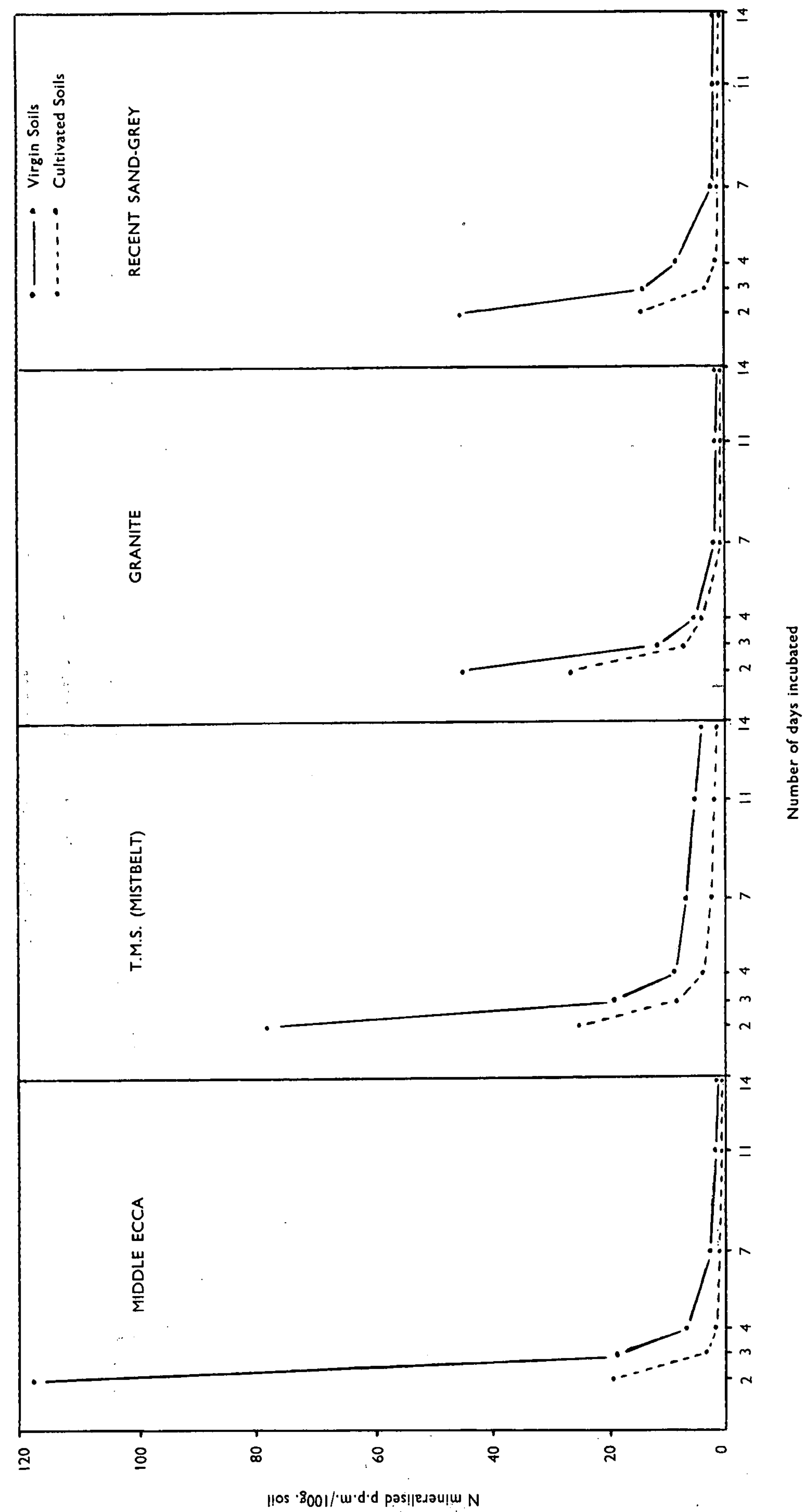

FIGURE 3 : Pattern of Nitrogen mineralisation with time.

Discussion and Conclusions

Table I pinpoints some of the main effects of cultivation on virgin soils, namely a marked decrease in the organic carbon and total nitrogen content (28.8 per cent) brought about by the rapid decomposition that occurs and a considerable increase in acidity associated with leaching of calcium ions, this probably being accelerated by the addition of fertilizers such as sulphate of ammonia.

The average percentage of C and N mineralised in the virgin soils was 3.0 and 5.7 respectively, while for the cultivated soils it was only 2.0 and 4.4. This indicates that the resistance of the soil organic matter to mineralisation increases with the degree of decomposition, and confirms results found elsewhere[10, 11].

Recently [8] more light has been shed on the nature of the nitrogen fraction in organic matter that is most susceptible to decomposition under cultivation. It has been found that the amino acid form of nitrogen (which represents about half of the total nitrogen in virgin soils) accounts for 61 per cent of the nitrogen decrease. The soil organic nitrogen substances comprising the other half of the total nitrogen, contribute only 33 per cent of the nitrogen decrease.

After following the decomposition over a four-year period of ryegrass labelled with C-14, Jenkinson[6] found that after a year, a fraction of the soil organic matter which he refers to as the 'soil biomass', had a specific activity ten times that of the soil organic matter as a whole. He suggests the existence of 'labile' and 'stable' organic matter fractions, the size of the former in a soil providing an excellent measure of its 'mineralisation potential'.

The studies described in this paper support this hypothesis, as the virgin soils have been shown to possess a much higher mineralisation potential than their cultivated counterparts, from which it could be concluded that they will contain a much larger pool of labile organic material or easily decomposed biomass.

Summary

Mineralisation studies were carried out on adjacent pairs of virgin and cultivated soils representative of several main soil groups within the Sugar Belt.

Large differences in N mineralised were shown to exist between the virgin and cultivated soils, ranging from 370-1610 lb. sulphate of ammonia per acre equivalent in the former, to 230-630 lb. in the latter, over a two week incubation period.

A highly significant correlation was shown to exist between the amounts of C and N mineralised in both the virgin and cultivated soils.

Patterns of decomposition over a two-week period, in both virgin and cultivated soils were similar, C and N mineralisation declining rapidly after the second day, though the initial flush of mineralisation was much larger in the virgin soils.

Immobilisation effects due to added carbon were shown to be much more severe on the cultivated soils.

The results are discussed with regard to the main effects of cultivation on virgin soils, and the nature of the nitrogen fraction in organic matter most susceptible to decomposition.

Acknowledgment

The author wishes to thank Mr. R. T. Bishop for the chemical analyses supplied for the soils used in this study.

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Mr. Wyatt: A few years ago I had the privilege of studying soil nitrogen in some detail, and this work included an investigation which considered, among other things, mineralization.

I would like to give a brief summary of a paper presented before Division S.3, Soil Science Society of America, in 1963. Dr. W. H. Patrick of Louisiana State University was the principal author of this paper, but I was privileged to conduct some of the laboratory investigations involved.

The title of the paper is "Soil Nitrogen Loss as a Result of Alternate Submergence and Drying" and the main purpose of this study was to investigate the nitrogen loss from a soil carried through several successive floodings and dryings.

Very briefly the methods involved placing weighed amounts of soil, in this case a Crowley silt loam, in test tubes and subjecting these samples to the following treatments:

Treatment (1) Maintaining the soil at optimum moisture throughout the experiment.

Treatment (2) Alternately submerging and drying the soil through several reduced and oxidized cycles.

Treatment (3) Maintaining the soil in a reduced condition by keeping it completely submerged.

Several experiments involving these treatments were conducted, and at frequent intervals samples were withdrawn and analysed for total nitrogen, ammonia nitrogen and nitrate nitrogen. In addition organic carbon was analysed in one experiment, and also oxidation-reduction or Redox potential measurements were taken.

To take the results of just one experiment, we found that after seven cycles of submergence and drying, a soil that originally contained 988 p.p.m. total nitrogen, lost more nitrogen as a result of alternate flooding and drying, viz. 206 p.p.m., than was produced as nitrate in the continuously well aerated treatment; viz. 130 p.p.m. Since the pathway of nitrogen loss from the soil under the conditions of this experiment very likely involved the formation of nitrate and its subsequent denitrification, it appears that more organic nitrogen was mineralized in the alternately submerged and dried soil than in the continuously well aerated soil.

Summarizing some of our findings it was found that large losses of nitrogen, up to 20 per cent of the total soil nitrogen, or 400 lb./acre furrow slice, were measured as a result of repeated cycles of submergence and drying. Most of the loss occurred during the 1st, 2nd or 3rd cycles. No loss of nitrogen was measured from soil kept at optimum moisture. Approximately 20 per cent of the total organic carbon was mineralized during five cycles of wetting and drying. The rate of reduction of NO_3 nitrogen after submergence was associated with the amount of readily decomposable organic matter in the soil.

This study thus indicates that severe nitrogen loss can occur in normally well drained soils that are temporarily waterlogged as a result of excess rain or impeded drainage. Of practical significance, therefore, is the necessity to allow for adequate drainage in our soils, especially if there is a supply of readily decomposable organic matter, such as appears to be the case in virgin soils when first brought under cultivation.

Although of a somewhat different nature, the results of this study agree very closely in certain respects with the findings published today in Mr. Wood's paper, especially with regard to the correlation between amounts of carbon and nitrogen mineralized in a soil.

It is indeed gratifying to know that this type of study is being conducted on the soils of our sugar belt and it is most interesting to note the difference between virgin and old cultivated soils. I am sure that at last we are on the threshold of a far better understanding of the controversial subject of nitrogen fertilization. From these mineralization studies and consequent studies already being conducted on several different soil types throughout the industry, we are going to be able to predict and recommend far more effectively the most beneficial amount of nitrogen to apply to each individual soil.

Mr. R. A. Wood: We may be experiencing considerable nitrogen loss from soils at present through denitrification, not only because of temporary waterlogging but also because of aerobic denitrification. It has been found that under grass lands considerable nitrogen losses occur under conditions that would be regarded as aerobic, because the large number of roots found under grasses reduce the oxygen in the soil considerably so that bacteria in the soil have to obtain their oxygen from other sources, nitrate being an obvious one. If this can happen under grasses it can happen under cane.

Mr. Hill: Does supplementary irrigation affect mineralisation?

Mr. R. A. Wood: If the soil is very dry before the irrigation one would expect nitrogen to be released when the irrigation takes place. Of course over-irrigation might also cause water-logging with subsequent denitrification.

Mr. Gosnell: In Table 2 of Mr. Wood's paper it appears that in cultivated soils red dolerite mineralises at twice the rate of Lower Ecca, but in the virgin soils it is only half.

Mr. R. A. Wood: This can be answered I think by referring to the degree of microbiological activity of these two soils as shown in Table 2 of Dr. Roth's paper. This indicates only a small difference in activity between the virgin and cultivated red dolerite soils compared with a very large difference in the Lower Ecca soils, which in turn can be related to the amount of readily decomposable substrata present.