INCUBATION STUDIES OF NITROGEN METABOLISM IN THREE SOILS FROM BANGLADESH

by

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THESIS

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ABSTRACT

Changes in mineral nitrogen levels and carbon dioxide release due to a variety of treatments were studied during incubation of Gangetic alluvial soils (pH 7.6 - 8.0), Brahmaputra alluvial soils (pH 7.4 - 7.8) and Red soils (pH 5.1 - 5.2) from Bangladesh.

The treatments involved the effects of adding various nitrogen sources (ammonium sulphate, urea, dried blood and hoof and horn) and organic materials (grass and straw). The effects of altering soil pH by addition of sulphur and calcium carbonate, of addition of varying levels of sodium as chloride and sulphate and of varying moisture contents and temperature during incubation were also studied. In addition, the extent of fixation of ammonium by the clay fractions and mineralization of fixed ammonium during subsequent incubation, extent of denitrification during waterlogged incubation of soils, and effect of period of air-dry storage on mineral nitrogen levels and mineralizable nitrogen during subsequent incubation were determined.

Although the Gangetic alluvial and Brahmaputra alluvial soils often showed similar responses to the treatments, there were sometimes significant and important differences between these two soils. The Red soils usually behaved quite differently from the other two soil types. Evidence was obtained that nitrification in the Red soils was due to both autotrophic and heterotrophic processes.

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D E D I C A T I O N

This thesis is dedicated to the memory of my late

Mother and Father

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CHAPTER 1

INTRODUCTION

LITERATURE REVIEW

SCOPE OF THE PRESENT STUDY

CHAPTER 1

INTRODUCTION

The present work reports on studies of nitrogen transformations during incubation of three types of soil from Bangladesh. All three types (Gangetic alluvium, Brahmaputra alluvium and Red soil) are important from the agricultural point of view. Since nitrogen is the main factor limiting plant growth in these soils, as in most tropical countries, it was considered that studies of factors affecting nitrogen changes would be of value. In addition the differential behaviour of the three soils with respect to the various imposed treatments would be of interest.

LITERATURE REVIEW

GENERAL

Most of the nitrogen present in soils is in organic combination (Proteinaceous compounds and their derivatives; 1,2), which form cannot be used by plants. Many types of heterotrophic microorganisms can attack these organic nitrogenous compounds in a series of reactions which convert part of the nitrogen to ammonia. This process is called ammonification or nitrogen mineralization. The organisms concerned are bacteria, fungi and actinomycetes (1, 3, 4, 5). The conversion takes place in a series of enzymatic reactions involving the breakdown of proteins through proteases, peptones, polypeptides and amino-acids (1, 6, 7, 8, 20).

The ammonia formed is converted by the two-stage autotrophic process (involving Nitrosomonas and Nitrobacter) through nitrite to nitrate. This process is called nitrification.

When decomposable materials are added to soil they are attacked by heterotrophic microorganisms which assimilate ammonia and nitrate.

This process is called immobilization of mineral nitrogen.

Under conditions of restricted aeration (anaerobic conditions) such as induced by waterlogging, nitrate can be decomposed by denitrifying bacteria to produce elementary nitrogen and oxides of nitrogen. The process, called denitrification, is stimulated by the presence of decomposable organic materials (1).

In soils of high pH ammonia may be lost by volatilization, particularly where application of ammonium or ammonium-forming fertilizers (urea and oxamide) are applied (1, 16 to 20). This process is called ammonia volatilization.

Ammonium ions can be held in the soil in fixed form by the layer lattice clay minerals. This ammonium, by definition, is that which cannot be extracted from soil by cation exchange reagents. The process is called ammonium fixation (22 to 25).

FACTORS AFFECTING NITROGEN CHANGES IN SOILS

AMMONIFICATION

Moisture and Aeration

Moisture content and aeration are intimately related in soils. At high moisture contents and particularly in waterlogged soils aeration is poor and ammonification continues, since many heterotrophic microorganisms can function in the absence of oxygen. Ammonium-nitrogen will therefore accumulate, since autotrophic nitrification cannot occur under anaerobic conditions (26, 27, 28).

pH

Ammonification occurs over a wide range of soil pH (34, 35). However, in general the process is more rapid in approximately neutral than in acid soils, whilst under alkaline conditions the rate tends to decrease (1, 15, 36 to 39).

Temperature

Slight ammonification occurs even at 2° and increases with temperature to a maximum ranging from 40° to 60° (1, 40 to 45). Above 40° thermophillic organisms are responsible for ammonification (46).

NITRIFICATION

Moisture and Aeration

Since oxygen is required for autotrophic nitrification those factors (high moisture content or compacted soils; 1, 55, 56) which restrict the movement of oxygen will decrease nitrification rate. Nitrification is restricted at low moisture contents even when aeration is adequate. The moisture content for maximum nitrification varies considerably among soils, ranging from 20% to 80% saturation (1, 30, 31, 57 to 64).

pH

Nitrification is usually absent or slight below pH 5, but increases with pH. The optimum pH for nitrification has been reported as ranging from 6.5 to 9.0 (35, 72 to 75). The maximum pH above which no nitrification occurs has been reported as 7.8 to 10.3 (66, 76 to 83). In rare cases nitrification has been reported even in soils of pH 3.9 to 4.7 (21, 71). This may be due to heterotrophic nitrification or to acid-adapted strains of autotrophic nitrifiers (1, 21).

Temperature

Nitrification rate is very slow below 5°, increases with temperature to a maximum ranging from 25° to 37° and falls off very rapidly with further increasing temperature (1, 57, 84 to 99). The occurrence of nitrification even at 60° in a Bangladesh tea soil

suggests that heterotrophic nitrification may be operative (21).

NITROGEN IMMOBILIZATION

The extent of microbial assimilation of mineral nitrogen during decomposition of organic materials added to soils depends mainly on the carbon/nitrogen (C/N) ratio of the added materials. The critical C/N ratio above which immobilization occurs has been reported as ranging from 20 to 25 (1, 35, 124). The extent and rate of immobilization varies with the nature of the added material, and is dependent on the degree of resistance of the added material to microbial attack (125 to 128). Some workers (129 to 135) found that ammonium-nitrogen was immobilized in preference to nitrate-nitrogen by the soil microorganisms when both forms of mineral nitrogen were present, whilst others (126, 136, 137) found the reverse to be the case.

AMMONIA VOLATILIZATION

Moisture content

In general volatilization of ammonia, where pH is sufficiently high to induce this loss, is high at low soil moisture content and decreases with increasing moisture content. However, loss of ammonia by volatilization has been reported even from waterlogged soils (62, 146 to 150).

pH

Negligible loss of ammonia by volatilization occurs at pH levels less that about 7, but losses increase considerably with increasing pH above 7 (16, 17, 117, 138 to 145).

Temperature

Volatilization of ammonia increases with soil temperature (140, 141, 146, 147, 148, 151, 152, 162). Increasing soil temperature

favours the shift in the equilibrium adsorbed ammonium $\rightleftarrows$ ammonium in solution to the right and this favours the loss of ammonia by volatilization.

Ammonia volatilization is greater where urea than where ammonium sulphate is applied. This is because urea hydrolyses in soils fairly rapidly to ammonium carbonate resulting in increased soil pH which encourages ammonia volatilization, whereas ammonium sulphate does not increase soil pH initially (17, 62, 109, 123, 139 to 141, 146 to 149, 153). Application of these materials a few inches below the soil surface rather than on the surface decreases loss of ammonia by volatilization (20, 140, 141, 153 to 158). Ammonia volatilization losses decrease with increasing soil clay content (17, 109, 159, 160).

AMMONIUM FIXATION

The extent of ammonium fixation varies with the amount and type of clay mineral present and decreases in the order illite, montmorillonite, kaolinite (186 to 190). Fixation of added ammonium-nitrogen is usually absent or low in moist soil but increases on drying the soil at ordinary and, in particular, at elevated temperatures (191 to 194). Fixation is particularly high with drying at 100^{o} (191 to 207). The extent of ammonium fixation sometimes tends to increase with pH (191, 199, 208 to 210). Fixation decreases with increasing soil organic matter content (211 to 214).

FACTORS AFFECTING CARBON DIOXIDE RELEASE FROM SOILS (CARBON MINERALIZATION)

Carbon mineralization is carried out by a wide range of heterotrophic microorganisms which attack the organic matter deposited in or on the soil (1, 76). Organic matter decomposition serves two

functions for the microflora, providing energy for growth and supplying carbon for the formation of new cell material. Under aerobic conditions 20 to 40% of the substrate carbon is assimilated; the remainder is released as carbon dioxide to the atmosphere or accumulated as waste products. In general the fungal flora release less carbon dioxide for each unit of carbon transformed aerobically than do the other microbial groups, as fungi are more efficient in their metabolism. Since organic carbon degradation is the work of all heterotrophs, it is commonly used to indicate the level of microbial activity. In incubation tests under aerobic conditions mineralization of carbon and nitrogen are usually correlated (164 to 168). Since the activity of microorganisms is influenced by the temperature and moisture content of the soil variations in these affect the evolution of carbon dioxide. Although release can proceed to a limited extent even at low temperatures, it increases with temperature (1, 21, 169). Carbon dioxide release increases with soil moisture content to a maximum at 50 to 100% saturation (21, 169, 170, 176). Where anaerobic conditions arise (near or above 100% saturation) carbon dioxide release is decreased and pyruvic acid, lactic acid and methane may be produced (1, 171, 172). Carbon dioxide release increases with soil pH (1). Where mineral nitrogen is limiting the activity of the microorganisms, addition of mineral nitrogen increases carbon dioxide release.

EFFECTS OF SALTS ON NITROGEN MINERALIZATION IN SOILS

In 1911 Lipman (173) found that the addition of chloride, sulphate and carbonate of sodium at some levels decreased N mineralization and nitrification in soils. Greaves (174) found that soil texture and moisture content influenced the relative toxicity of

different salts. A sandy soil was more sensitive to salt toxicity than was a loam soil, and toxicity at a particular salt level decreased with increasing moisture content. Brown and Hitchcock (175) and Sindhu (176) found that low concentrations of some salts stimulated nitrification although higher concentrations inhibited the process. Brown and Johnson (177) found that N mineralization was inhibited by 0.5% sodium sulphate.

SCOPE OF THE PRESENT STUDY

This study reports on changes in mineral nitrogen during incubation of three types of soils from Bangladesh. Changes in mineral N involved mineralization (as ammonium-, nitrite- and nitrate-N), immobilization, ammonium fixation, ammonia volatilization and denitrification, and suitable experiments were set up to study these changes. The main factors studied were the effects of addition of inorganic N fertilizers, decomposable organic materials and soluble salts, alteration of soil pH and varying soil temperature and moisture contents. Carbon dioxide release during incubation was also determined in some experiments as a measure of carbon mineralization. Incubation methods were used to obtain good control of temperature and moisture conditions.

CHAPTER 2

MATERIALS AND METHODS

Characteristics of the soils

Incubation methods

Extraction methods

Analytical methods

CHAPTER 2

MATERIALS AND METHODS

Three Gangetic alluvial soils (G1, G2, G3), three Brahmaputra alluvial soils (B1, B2, B3) and two Red soils from the Dacca district of Bangladesh were used. For each soil small samples were taken at random over several acres from the upper 9 inches. The combined samples for each soil were air-dried and passed through a 1 mm sieve, particles greater than 1 mm being rejected. The soils were despatched to the United Kingdom in polythene bags.

Rice, jute and sugarcane are the main crops grown on the Gangetic and Brahmaputra alluvial soils. The Red soil is used mainly for horticultural crops.

Properties of the eight soils are shown in Table 1. pH was determined after shaking 10g of soil with 10 ml of water. Organic carbon was determined by the Walkley-Black method (222, 223). Calcium carbonate was determined in a calcimeter. For mechanical analysis the soil was dispersed in 0.1N sodium hydroxide containing 0.5% calgon (sodium hexametaphosphate) after destroying organic matter by boiling with hydrogen peroxide. The silt and clay were determined by an hydrometer method. Total nitrogen was determined by digestion of the soil with concentrated sulphuric acid, potassium sulphate and copper sulphate, the ammonium formed being determined by steam distillation into boric acid following addition of excess sodium hydroxide. Cation exchange capacity was determined by the ammonium acetate method.

Clay Mineralogy

(The author is indebted to Dr. A. H. Weir and Dr. J. Catt of Rothamsted Experimental Station for these analyses).

The minerals present in the clay fraction (< 0.002 mm) of the Gangetic

TABLE 1

CHARACTERISTICS OF THE SOILS

G Gangetic alluvial soils
B Brahmaputra alluvial soils
R Red soils

Soil	pH*	$CaCO_3$ %	org.C %	Sand %	Silt %	Clay %	CEC** me%	Total N %
G1	7.6	0.00	0.55	38	38	24	22.9	0.081
G2	7.9	6.00	0.48	41	37	22	24.3	0.071
G3	8.0	0.27	0.33	68	22	10	9.7	0.048
B1	7.4	0.00	0.56	40	40	20	19.5	0.076
B2	7.8	0.30	0.30	84	11	5	8.8	0.046
B3	7.8	0.00	0.42	71	21	8	15.4	0.049
R1	5.2	0.00	0.55	52	22	26	18.0	0.069
R2	5.1	0.00	0.54	53	20	27	16.8	0.068

* in water

** cation exchange capacity (m.equiv. per 100g)

and Brahmaputra alluvial soils were similar with respect to type and quantity. Illite, vermiculite and interstratified smectite-illite were the main minerals and small amounts of chlorite and kaolinite were also present. The clay fraction of the Red soil contained mainly mica, kaolinite and vermiculite, and small amounts of quartz and goethite.

INCUBATION METHODS

Incubation was done in 4 in. by 1 in. diameter flat-bottomed glass tubes using 10g of air-dried, 1 mm sieved soil. Distilled water was added to give a particular moisture content based on the saturation capacity of each soil. Saturation capacity was determined by placing 10g of soil in a dry porcelain crucible with sintered bottom and weighing. The crucible was then placed in a dish of water so that the water in the dish was at the same level as that of the sintered bottom. The water is absorbed into the soil by capillary action and 20 minutes after the top of the soil appeared moist the crucible was removed, the outside was dried and it was weighed. To allow for water absorbed by the sintered bottom, an empty crucible was subjected to the same treatment. The amount of water absorbed by 10g of soil is 100% saturation, and this represents a pF of zero.

Where water-soluble materials (e.g. ammonium sulphate, urea) were added before incubation, these were dissolved at a suitable concentration in the water used to bring 10g of soil to a particular % saturation. Where water-insoluble materials (e.g. straw, dried blood) were added, these were finely ground and mixed with dry soil in bulk at specified levels. 10g portions were then weighed into incubation tubes, after which water was added to the specified saturation. The barium peroxide method (226) was used for aeration and absorption of evolved carbon dioxide during incubation of the tubes which were closed

with rubber bungs. All incubation treatments were in duplicate.

EXTRACTION METHODS

After incubation sufficient water was added to bring the total water content to 10 ml and, after closing the tube with a rubber bung and shaking for 30 seconds, pH was measured. Then 10 ml of 2N-potassium chloride was added and the tube was shaken for 2 minutes. After centrifuging the supernatant liquid was poured into a small funnel plugged with cotton wool and the filtrate was collected in a clean dry receiver. Suitable aliquots were used for determining mineral nitrogen.

ANALYTICAL METHODS FOR MINERAL-NITROGEN FORMS

Ammonium- and nitrate-N in the potassium chloride extracts were determined by the microdiffusion method (227). Ammonia was determined by reaction with magnesium hydroxide suspension. Ammonia plus nitrate was determined by reaction with magnesium hydroxide mixed with titanous and ferrous sulphates, with sufficient excess magnesium hydroxide to produce titanous and ferrous hydroxide. In this way nitrate was reduced to ammonia.

Nitrite was determined in a separate aliquot of the extract by a colorimetric method using sulphanilic acid and N-(1-naphthyl)-ethylenediamine-dihydrochloride (229).

Ammonia volatilization during incubation was determined by placing a small vial containing 1 ml of 0.1N sulphuric acid on the soil in the incubation tube. The absorbed ammonia was determined by microdiffusion.

CHAPTER 3

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION OF G, B AND R SOILS ALONE AND AFTER TREATMENT WITH AMMONIUM SULPHATE AND UREA

Experiment 1

Nitrogen and carbon mineralization during incubation (3 and 6 weeks) of G1, B1 and R1 soils alone and with addition of ammonium sulphate (50 ppm N).

Experiment 2

Nitrogen and carbon mineralization during incubation (2 and 6 weeks) of G1, B1 and R1 soils alone and with addition of ammonium sulphate and urea (100 ppm N).

Experiment 3

Nitrogen mineralization during incubation (2 and 6 weeks) of G2 soil (calcareous) alone and with addition of ammonium sulphate and urea (100 ppm N).

CHAPTER 3

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION OF G, B AND R SOILS ALONE AND AFTER TREATMENT WITH AMMONIUM SULPHATE AND UREA

Since ammonium sulphate and urea are the two main sources of nitrogen used in Bangladesh, this chapter reports on three experiments using these materials. In Experiment 1 50 ppm N as ammonium sulphate was added, whilst in Experiment 2 100 ppm N as ammonium sulphate and urea were added. The G1, B1 and R1 soils in these two experiments contained no calcium carbonate. In order to assess the effects of the presence of calcium carbonate, the G2 soil (containing 6% calcium carbonate) was used in Experiment 3, with the same nitrogen treatments as given in Experiment 2.

EXPERIMENT 1

Nitrogen and carbon mineralization during incubation (3 and 6 weeks) of G1, B1 and R1 soils alone and with addition of ammonium sulphate (50 ppm N).

METHODS

The ammonium sulphate was added dissolved in the water used to bring the moisture content to 50% saturation (an aerobic moisture content). Sufficient incubation tubes using 10g portions of soil (control and treated) were set up to allow for analysis initially and after 3 and 6 weeks of incubation.

RESULTS

Table 2 shows results for ammonium-, nitrate- and mineral-N levels and accumulation values initially and after 3 and 6 weeks of incubation. Negative accumulation values indicate less of a particular form of nitrogen after incubation than initially. pH values and carbon dioxide release values are also presented.

No ammonium sulphate added.

After 3 weeks of incubation the G1 and B1 soils accumulated more nitrate than did the R1 soil. During 3-6 weeks there was more accumulation of nitrate in the B1 and R1 than in the G1 soil. After 3 weeks mineral-N accumulation was similar in the G1 and R1 soils and somewhat higher in the B1 soil. There were similar trends over 3-6 weeks, except that the extra accumulation was highest in the B1 soil. After 3 weeks of incubation carbon dioxide release from the soils increased in the order R1, B1, G1. During 3-6 weeks the differences in carbon dioxide release among the three soils was much less than during the first 3-week period. Over 0-6 weeks the G1 soil produced more carbon dioxide than did B1 and R1.

Ammonium sulphate added

In the G1 and B1 soils only about half, whilst in the R1 soil all, the added ammonium-N was recovered initially by extraction with KCl. About half the added ammonium-N was nitrified in the G1 soil after 3 weeks and little further nitrification occurred to 6 weeks. In the B1 soil about one-third of the added ammonium-N was nitrified after 3 weeks and about half after 6 weeks. In the R1 soil about one-sixth of the added ammonium-N was nitrified after 3 weeks and about two-fifths after 6 weeks. Addition of ammonium sulphate to the G1 and B1 soils had no significant effects on carbon dioxide release during incubation, but there was a small, but significant effect in

TABLE 2

Chap. 3 Expt. 1

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION TO 6 WEEKS OF G1, B1 AND R1 SOILS ALONE AND WITH ADDITION OF AMMONIUM SULPHATE (50 ppm N)

(Results are given in ppm on dry soil basis)

Initial values

Soil	N added	NH_4-N	NO_3-N	min-N	pH
G1	0	6.0	13.0	19.0	7.5
"	50	29.1	12.5	41.6	7.5
B1	0	4.1	5.9	10.0	7.3
"	50	31.9	4.2	36.1	7.1
R1	0	10.2	4.5	14.7	5.2
"	50	59.3	4.3	63.6	5.2

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
Soil	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
G1	0	0.6	38.6	39.2	7.9	- 5.4	25.6	20.2
"	50	0.7	62.5	63.2	7.9	-28.4	50.0	21.6
B1	0	1.4	32.2	33.6	7.0	- 2.7	26.3	23.6
"	50	1.7	47.8	49.5	7.0	-30.2	43.6	13.4
R1	0	11.9	22.4	34.3	4.8	1.7	17.9	19.6
"	50	47.6	30.8	78.4	4.7	-11.7	26.5	14.8
		After 6 weeks incubation						
G1	0	0.7	41.8	42.5	7.9	- 5.3	28.8	23.5
"	50	1.4	69.9	71.3	7.9	-27.7	57.4	29.7
B1	0	1.0	43.3	44.3	6.7	- 3.1	37.4	34.3
"	50	1.3	65.0	66.3	6.7	-30.6	60.8	30.2
R1	0	7.0	33.3	40.3	4.5	- 3.2	28.8	25.6
"	50	30.8	51.8	82.6	4.5	-28.5	47.5	19.0

CARBON DIOXIDE RELEASE (weeks)

Soil	N added	0-3	3-6	0-6
G1	0	1390	530	1920
"	50	1415	585	2000
B1	0	1045	435	1480
"	50	1140	440	1580
R1	0	820	475	1295
"	50	910	520	1430

L.S.D.($P < 0.05$) NH_4-N 1.5, NO_3-N 2.5, min-N 2.9 and CO_2 109

increasing it from the R1 soil.

pH

With each soil, addition of ammonium sulphate had negligible effects in altering pH initially or after 3 and 6 weeks of incubation compared with the control soil. Incubation increased the pH of the G1 soil and decreased the pH of B1 and R1.

DISCUSSION

Whereas in the R1 soil all the ammonium added as ammonium sulphate was recovered initially by extraction with potassium chloride, only about half of that applied to the G1 and B1 soils was recovered. This indicates that ammonium fixation is operative in the two latter soils, even under wet conditions. The lower nitrate in the B1 than in the G1 soil up to 3 weeks of incubation suggests that ammonium fixed by the B1 soil was less easily nitrified than that fixed by the G1 soil during this period. However, after further 3 weeks of incubation virtually no further nitrate was produced by the G1 soil but a moderate amount was produced by the B1 soil. This suggests that nitrification of fixed ammonium in the B1 soil was subject to a lag phase. In the R1 soil even though no ammonium fixation occurred initially, nitrification was much slower than in the other two soils. This is because the R1 soil had a much lower pH (5.2) than the G1 (pH 7.5) and B1 (pH 7.2) soils and it is well-known that autotrophic nitrification rate decreases with decreasing pH.

The wet fixation of ammonium by G1 and B1 soils is not surprising since vermiculite is one of the main clay minerals present in these two soils and it is known that vermiculite can fix ammonium even under wet conditions (197, 200). The R1 soil

contained only a trace of vermiculite and did not fix ammonium initially under wet conditions. This is probably also due to the low pH of R1, since fixation is known to decrease with decreasing soil pH (185, 199).

Even though the three soils had virtually the same level of organic carbon, carbon dioxide release during incubation decreased in the order G1, B1, R1. This indicates that organic carbon compounds were most resistant to decomposition by heterotrophic organisms in R1 and least resistant in G1. R1 was the only soil to show a small, though significant increase in carbon dioxide release due to addition of ammonium sulphate. This suggests that only in the R1 soil was the activity of the heterotrophs responsible for carbon mineralization being limited by mineral nitrogen.

EXPERIMENT 2

Nitrogen and carbon mineralization during incubation (2 and 6 weeks) of G1, B1 and R1 soils alone and with addition of ammonium sulphate and urea (100 ppm N).

METHODS

Ammonium sulphate and urea were mixed with the soils in finely ground solid form to supply 100 ppm N on the dry soil basis, and water was added to 50% saturation. In this experiment, in addition to determining ammonium and nitrate, nitrite accumulation and ammonia volatilization were also determined.

RESULTS

No ammonia volatilization or nitrite accumulation occurred in any of the soils with any treatment. Results for ammonium and nitrate levels and accumulation, pH, and carbon dioxide release are shown in Table 3A (G1 soil), Table 3B (B1 soil) and Table 3C (R1 soil).

Initial values for mineral N in the G1 soil showed that only 42% of the added ammonium was recovered in exchangeable form. In the B1 soil 62% and in the R1 soil 97% of the added ammonium was recovered. In the G1 soil about one-third of the ammonium sulphate and urea were converted to nitrate with up to 2 weeks of incubation and there was no further nitrification up to 6 weeks. In the B1 soil there was no nitrification of ammonium sulphate up to 2 weeks, but 27% nitrification up to 6 weeks. Urea was nitrified to the extent of 28% up to 2 weeks and 32% after 6 weeks. In the R1 soil there was no nitrification of ammonium sulphate or urea up to 2 or 6 weeks. In fact, ammonium sulphate addition inhibited nitrification.

TABLE 3A

Chap. 3 Expt. 2

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION (2 and 6 weeks) OF G1 SOIL ALONE AND WITH ADDITION OF AMMONIUM SULPHATE AND UREA (100 ppm N)

(Results are given in ppm on dry soil basis)

Initial values

Treatment	NH_4-N	NO_3-N	min-N	pH
Control	5.9	12.0	17.9	7.5
Ammo Sulph.	48.0	14.3	62.3	7.4
Urea	17.1	13.7	30.8	7.4

	L E V E L S				ACCUMULATION		
	After 2 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
Control	1.4	34.3	35.7	7.8	- 4.5	22.3	17.8
Ammo Sulph.	1.9	70.2	72.1	7.6	-46.1	55.9	9.8
Urea	1.4	74.2	75.6	7.7	-15.7	60.5	44.8
	After 6 weeks incubation						
Control	0.8	43.3	44.1	8.1	- 5.1	31.3	26.2
Ammo Sulph.	1.0	78.9	79.9	8.0	-47.0	64.6	17.6
Urea	0.8	74.2	75.0	8.0	-16.3	60.5	44.2

CARBON DIOXIDE RELEASE (weeks)

Treatment	0-2	2-6	0-6
Control	1155	860	2015
Ammonium sulphate	1165	1385	2550
Urea	1255	1405	2660

L.S.D. ($P < 0.05$) NH_4-N 1.8, NO_3-N 2.5, min-N 2.5 and CO_2 206.

TABLE 3B

Chap. 3 Expt. 2

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION (2 and 6 weeks) OF B1 SOIL ALONE AND WITH ADDITION OF AMMONIUM SULPHATE AND UREA (100 ppm N)

(Results are in ppm on dry soil basis)

Initial values

Treatment	NH_4-N	NO_3-N	min-N	pH
Control	3.9	5.5	9.4	7.2
Ammo.sulph.	66.5	7.1	73.6	6.9
Urea	9.0	7.2	16.2	7.2

	L E V E L S				ACCUMULATION		
	After 2 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
Control	0.6	29.6	30.2	7.0	- 3.3	24.1	20.8
Ammo.sulph.	15.4	23.8	39.2	6.8	-51.1	16.7	-34.4
Urea	3.9	57.4	61.3	7.0	- 5.1	50.2	45.1
	After 6 weeks incubation						
Control	0.6	39.5	40.1	6.9	- 3.3	34.0	30.7
Ammo.sulph.	2.1	68.6	70.7	6.4	-64.4	61.5	- 2.9
Urea	1.1	74.3	75.4	6.9	- 7.9	66.0	58.1

CARBON DIOXIDE RELEASE (weeks)

Treatment	0-2	2-6	0-6
Control	980	555	1535
Ammo.sulph.	1045	765	1810
Urea	1180	620	1800

L.S.D. ($P < 0.05$) NH_4-N 1.7, NO_3-N 2.2, min-N 2.6 and CO_2 201.

TABLE 3C

Chap. 3 Expt. 2

NITROGEN AND CARBON MINERALIZATION DURING INCUBATION (2 and 6 weeks) OF R1 SOIL ALONE AND WITH ADDITION OF AMMONIUM SULPHATE AND UREA (100 ppm N)

(Results are in ppm on dry soil basis)

Initial values

Treatment	NH_4-N	NO_3-N	min-N	pH
Control	10.6	4.4	15.0	5.2
Ammo.sulph.	107.7	4.6	112.3	4.9
Urea	14.0	4.6	18.6	5.1

	L E V E L S				ACCUMULATION		
	After 2 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
Control	16.8	13.7	30.5	4.9	6.2	9.3	15.5
Ammo.sulph.	109.2	13.3	122.5	4.9	1.5	8.7	10.2
Urea	95.2	11.2	106.4	5.2	81.2	6.6	87.8
	After 6 weeks incubation						
Control	7.4	31.9	39.3	4.6	-3.2	27.5	24.3
Ammo.sulph.	114.8	11.2	126.0	4.7	7.1	6.6	13.7
Urea	106.4	28.6	135.0	4.9	92.4	24.0	116.4

CARBON DIOXIDE RELEASE (weeks)

Treatment	0-2	2-6	0-6
Control	885	950	1835
Ammo.sulph.	1060	525	1525
Urea	1030	715	1745

L.S.D. ($P < 0.05$) NH_4-N 3.0, NO_3-N 1.5, min-N 3.4 and CO_2 108.

In the G1 soil there were negligible levels of ammonium after 2 and 6 weeks with both treatments. In the B1 soil there was a higher ammonium level after 2 weeks with ammonium sulphate than with urea, but by 6 weeks levels were low with both treatments. In the R1 soil ammonium levels were high after both periods, somewhat more so with ammonium sulphate than with urea.

Carbon dioxide release from the G1 and B1 soils was increased to about the same extent by addition of ammonium sulphate and urea. However, in the R1 soil, whereas both forms of added N increased carbon dioxide release over 0-2 weeks, over 2-6 weeks ammonium sulphate decreased carbon dioxide release to a greater extent than did urea. Over the 0-6 weeks period ammonium sulphate decreased carbon dioxide release somewhat, whilst urea had no significant effect.

The pH of the G1 soil increased with incubation time irrespective of treatment, whilst in the B1 and R1 soils pH decreased slightly with time. In the R1 soil ammonium sulphate had no effect on pH, whilst urea increased it slightly with incubation time.

DISCUSSION

In the G1 soil most of the nitrification of added ammonium sulphate and urea which occurred did so during the first two weeks. On the other hand in the B1 soil nitrification of ammonium sulphate occurred only during the 2-6 week incubation period, whilst with urea most occurred during the 0-2 week period. The difference in response between B1 and G1 is most likely due to the higher pH of G1 attained during the 2-6 week period. A likely reason for this is that in the

B1 soil the initial 100 ppm N added as ammonium sulphate was toxic to nitrification during the first 2 weeks but was readily nitrified during the 2-6 week period. In the B1 soil it is possible that nitrite was formed during the first few days of incubation and it is known that nitrite is toxic to both Nitrosomonas and Nitrobacter. However, by 2 weeks nitrite had disappeared and by 6 weeks nitrate accumulation was only somewhat lower than where urea was added. The lower nitrate level after 6 weeks with ammonium sulphate than with urea suggests that with the former material some nitrogen may have been lost by decomposition of ammonium nitrite to nitrogen gas and water.

In the R1 soil no nitrate accumulated after 2 or 6 weeks from ammonium sulphate or urea. However by 6 weeks the nitrate level where ammonium sulphate was applied was considerably lower than in the control soil, suggesting that this form of N at 100 ppm inhibited nitrification of native organic nitrogen. It is worth noting that in Experiment 1, where only 50 ppm N as ammonium sulphate was added, this inhibitory effect did not occur.

In the G1 and B1 soils 100 ppm N as ammonium sulphate or urea increased carbon dioxide release to about the same extent. This is in contrast to Experiment 1 where 50 ppm ammonium N had no effect on carbon dioxide release. It is likely that 100 ppm ammonium N stimulated the activity of the heterotrophs responsible for the decomposition of organic materials, whilst 50 ppm did not. In the R1 soil carbon dioxide release was increased to the same extent by both forms of N added at 100 ppm, but only during the first 2 weeks. During the 2-6 week period both forms of added N, but particularly ammonium sulphate, decreased carbon dioxide release, but over the 6 week period only ammonium sulphate decreased it. This appears to be related to the toxic effect of ammonium sulphate on nitrification during the 2-6 week period.

The possibility of the occurrence of heterotrophic nitrification, as well as autotrophic nitrification, in the acid R1 soil must be considered. Ishaque (21) obtained evidence for heterotrophic nitrification in a "Tea" soil (pH 4.2) from Bangladesh. Addition of ammonium sulphate decreased overall nitrification, suggesting an inhibitory effect on heterotrophic nitrification. Similar results were obtained in the present study with the R1 soil, where 100 ppm N addition as ammonium sulphate decreased overall nitrification.

EXPERIMENT 3

Nitrogen mineralization during incubation (2 and 6 weeks) of G2 soil (Calcareous) alone and with addition of ammonium sulphate and urea (100 ppm N)

METHODS

In order to determine the effects of calcium carbonate in soil on N mineralization, the G2 soil (containing 6.0% calcium carbonate) was set up with the same treatments as in Experiment 2 and the results compared with those obtained with the G1 soil in Experiment 2. Carbon dioxide release was not determined in this experiment (although the barium peroxide method was used for aeration) since it is known that an unknown proportion of the carbon dioxide released would come from the calcium carbonate, and this would not represent mineralization of carbon from organic materials.

RESULTS

These are shown in Table 4. There was no volatilization of ammonia with any of the treatments. Nitrite accumulated only during the first two weeks of incubation and then only with the ammonium sulphate treatment. Initially only 29% of the nitrogen applied as ammonium sulphate was recovered as exchangeable ammonium. With incubation up to 2 weeks nitrate was somewhat lower where ammonium sulphate than where urea was added, but the levels were similar for both N sources if nitrite was included with nitrate. After 6 weeks of incubation nitrate levels were also very similar with both forms of added N. With all treatments mineralized N accumulated entirely as nitrate (or nitrite) during the 0-2 and 2-6 week periods.

TABLE 4

Chap. 3 Expt. 3

NITROGEN MINERALIZATION DURING INCUBATION (2 and 6 weeks) OF G2 SOIL (calcareous) ALONE AND WITH ADDITION OF AMMONIUM SULPHATE AND UREA (100 ppm N)

(Results are in ppm, dry soil basis)

Initial values

Treatment	NH_4-N	NO_3-N	min-N	pH
Control	7.0	3.9	10.9	7.8
Ammo.sulph.	35.6	4.9	40.5	7.7
Urea	14.3	3.8	18.1	8.0

	L E V E L S					ACCUMULATION		
	After 2 weeks incubation							
Treatment	NH_4-N	NO_2-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
Control	1.7	0	30.2	31.9	7.8	- 5.3	26.3	21.0
Ammo. sulph.	2.0	8	53.7	63.7	7.6	-33.6	48.8	23.2
Urea	1.7	0	60.9	62.6	7.7	-12.6	57.1	44.5
	After 6 weeks incubation							
Control	1.7	0	39.3	41.0	8.2	- 5.3	35.4	30.1
Ammo. sulph.	1.6	0	76.9	78.5	8.1	-34.0	72.0	38.0
Urea	1.6	0	74.1	75.7	8.2	-12.7	70.3	57.6

L.S.D. ($P < 0.05$) NH_4-N 1.2, NO_3-N 2.0 and min.N 2.4.

DISCUSSION

In the G2 soil (6.0% calcium carbonate) initial fixation of ammonium from added ammonium sulphate was somewhat higher than in the G1 soil (no calcium carbonate). This suggests that the presence of calcium carbonate encourages fixation. It is also possible that the nature of the clays present may differ between the G1 and G2 soils and this could affect the extent of fixation of ammonium under wet conditions. The organic carbon content of the G1 soil is somewhat higher than that of the G2 soil. This could account for the higher ammonium fixation by the G2 soil, since it is known that organic matter can block fixation positions on clay particles.

The somewhat delayed nitrification of ammonium sulphate in the G2 compared with the G1 soil is probably due to release of volatile ammonia in the soil or formation of ammonium hydroxide, which inhibits the autotrophic oxidation of nitrite to nitrate (the temporary accumulation of nitrite confirms this) (113, 114, 115). The inhibitory effect is usually temporary and with further incubation normal nitrification occurs. The lack of nitrite accumulation in the G2 soil treated with urea is probably due to the fact that as urea-N is converted to ammonium-N it is rapidly nitrified, thus preventing any high accumulation of ammonia, which might inhibit nitrification.

SUMMARY OF CHAPTER 3

Experiment 1

Nitrogen and carbon mineralization during incubation over 6 weeks were determined in the G1, B1 and R1 soils without and with addition of ammonium sulphate (50 ppm N). Where no ammonium sulphate was added the G1 and B1 soils accumulated more nitrate than did the R1 soil up to 3 weeks, whilst during 0-6 weeks nitrate accumulation was greater in B1 than in G1 and R1. Over 0-3 and 0-6 weeks B1 accumulated slightly more mineral N than did G1 and R1. Over 0-6 weeks the G1 soil produced rather more carbon dioxide than did B1 and R1. Where ammonium sulphate was added about half the added ammonium-N was fixed initially by the G1 and B1 soils, but there was no initial fixation by the R1 soil. Most of the nitrification of added ammonium sulphate in the G1 soil occurred during the first 3 weeks, whilst in B1 and R1 nitrification was greater in the second than in the first 3-week period. Nitrification of added ammonium-N over 6 weeks increased in the order R1, G1, B1. Addition of ammonium sulphate had no or negligible effects on carbon dioxide release from all soils.

Experiment 2

Nitrogen and carbon mineralization during incubation over 6 weeks were determined in the G1, B1 and R1 soils without and with addition of ammonium sulphate and urea (100 ppm N). The B1 and G1 soils fixed about half the added ammonium initially, but there was no initial fixation by the R1 soil. In the G1 soil virtually all the nitrification of added ammonium which occurred (about one-third of the total) did so during the first 2 weeks. In B1 most of the nitrification of ammonium occurred during the 2-6 week period, whilst nitrification

of urea occurred mainly during the first 2 weeks. In the R1 soil there was no nitrification of ammonium or urea after either period. In fact ammonium addition inhibited overall nitrification, suggesting that heterotrophic nitrification was operative in the control soil, and that 100 ppm added ammonium-N inhibited this form of nitrification. In the G1 and B1 soils carbon dioxide release was increased to the same extent by ammonium sulphate and urea, whilst in the R1 soil it was decreased, but only by ammonium sulphate.

Experiment 3

The G2 soil, containing 6.0% calcium carbonate, was used so as to compare the results with those obtained with the G1 soil (Experiment 2), which had the same pH but contained no calcium carbonate. Treatments were the same as in Experiment 2. There was no volatilization of ammonia with any of the treatments. Nitrite-N accumulated (8 ppm) only with the ammonium sulphate treatment and then only in the 0-2 week period. With up to 2 weeks of incubation nitrate was somewhat lower where ammonium sulphate than where urea was added, but nitrite- + nitrate-N levels were very similar with both treatments, and this similarity persisted up to 6 weeks. Apart from the early nitrite accumulation in the G2 soil the results obtained after 6 weeks for nitrification of both forms of added N in the G1 and G2 soils were similar except that nitrate accumulation was slightly higher in G2.

CHAPTER 4

EXPERIMENT 4

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION OVER 12 WEEKS OF G1, B1 AND R1 SOILS TREATED WITH 0.5% STRAW AND GRASS

CHAPTER 4

EXPERIMENT 4

Mineral nitrogen changes and carbon dioxide release during incubation over 12 weeks of G1, B1 and R1 soils treated with 0.5% straw and grass

METHODS

Separate bulk samples of each soil were mixed with 0.5% straw and grass (less than 0.5 mm) and finely ground ammonium nitrate to supply 100 ppm N on the dry soil basis. The straw contained 0.68% N and 39.6% C, and the grass contained 3.53% N and 39.2% C. The ammonium nitrate was added to ensure that mineral N was not limiting the activity of the heterotrophs decomposing the organic materials. The control of each soil also received ammonium nitrate but no organic material. Sufficient incubation tubes were set up to allow for analysis in duplicate initially and after 2, 6 and 12 weeks of incubation at a moisture content of 50% saturation.

RESULTS

Table 5A presents mineral N levels. Table 5B presents accumulation values, obtained by subtracting initial values from those after each incubation period. Table 5C and Figure 1 present immobilization values obtained by subtracting, for each soil, the accumulation value in the control from those in the straw- and grass-treated soil. Negative values represent immobilization or less mineral N than in the control, whilst positive values represent more mineral N than in the control, indicating net mineralization. Table 5D and Figure 2 present carbon dioxide release. Table 5D also presents apparent carbon dioxide release from straw and grass, and the percent recovery of straw and grass carbon as carbon dioxide.

CHAPTER 4

Experiment 4

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION FOR 12 WEEKS OF G1, B1 and R1 SOILS TREATED WITH 0.5% STRAW AND GRASS AND AMMONIUM NITRATE (100 ppm N)

TABLE 5A (LEVELS)

(Results are given in ppm on dry soil basis)

		Initial values				After 2 weeks incubation			
Soil	Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N	pH
G1	Control	20.2	52.6	72.8	7.4	1.0	93.2	94.2	7.8
"	Straw	23.9	53.8	77.7	7.4	1.3	36.5	37.8	7.6
"	Grass	29.4	54.6	84.0	7.3	1.0	38.2	39.2	7.4
B1	Control	30.5	47.9	78.4	7.0	9.5	68.9	78.4	7.0
"	Straw	31.4	49.8	81.2	6.9	1.0	41.6	42.6	7.1
"	Grass	41.0	51.8	92.8	6.9	2.2	31.4	35.6	7.4
R1	Control	56.0	51.8	107.8	4.7	64.4	44.8	109.2	4.8
"	Straw	57.0	40.6	97.6	4.7	25.2	44.8	70.0	4.7
"	Grass	54.0	46.5	100.5	4.7	150.5	3.5	154.0	5.7
		After 6 weeks incubation				After 12 weeks incubation			
G1	Control	1.0	102.6	103.6	8.1	0.8	109.8	110.6	7.9
"	Straw	0.9	53.7	54.6	8.1	0.3	66.2	66.5	8.0
"	Grass	1.1	67.4	68.5	8.1	1.0	91.4	92.4	8.0
B1	Control	1.2	96.6	97.8	7.0	1.0	106.1	107.1	6.8
"	Straw	1.2	53.4	54.6	7.0	1.0	62.1	63.1	6.8
"	Grass	1.4	65.7	67.1	7.1	1.4	82.6	84.0	6.9
R1	Control	64.4	71.2	135.6	4.8	49.7	88.9	138.6	4.6
"	Straw	4.2	85.3	89.5	4.7	1.4	106.5	107.9	4.5
"	Grass	95.1	67.3	162.4	4.9	77.0	112.0	189.0	4.4

L.S.D. ($P < 0.05$) NH_4-N 1.9, NO_3-N 4.1 and min.N 4.3.

TABLE 5B

Chap. 5 Expt. 5

ACCUMULATION

After 2 weeks incubation

Soil	Treatment	NH_4-N	NO_3-N	min-N
G1	Control	-19.2	40.6	21.4
"	Straw	-22.6	-17.3	-39.9
"	Grass	-28.4	-16.4	-44.8
B1	Control	-21.0	21.0	0
"	Straw	-30.4	- 8.2	-38.6
"	Grass	-38.8	-20.4	-59.2
R1	Control	8.4	- 7.0	1.4
"	Straw	-31.8	4.2	-27.6
"	Grass	96.5	-43.0	53.5

After 6 weeks incubation

G1	Control	-19.2	50.0	30.8
"	Straw	-23.0	- 0.1	-23.1
"	Grass	-28.3	12.8	-15.5
B1	Control	-29.3	48.7	19.4
"	Straw	-30.2	3.6	-26.6
"	Grass	-39.6	13.9	-25.7
R1	Control	8.4	19.4	27.8
"	Straw	-52.8	44.7	- 8.1
"	Grass	41.1	20.8	61.9

After 12 weeks incubation

G1	Control	-19.4	57.2	37.8
"	Straw	-23.6	12.4	-11.2
"	Grass	-28.4	36.8	8.4
B1	Control	-29.5	58.2	28.7
"	Straw	-30.4	12.3	-18.1
"	Grass	-39.6	30.8	- 8.8
R1	Control	- 6.3	37.1	30.8
"	Straw	-55.6	65.9	10.3
"	Grass	23.0	65.5	88.5

L.S.D ($P < 0.05$) NH_4-N 1.9, NO_3-N 4.1 and min-N 4.3

TABLE 5C

Chap.4 Expt. 4

IMMOBILIZATION VALUES FOR STRAW AND GRASS

(Results are in ppm on dry soil basis)

After 2 weeks incubation

Soil	Treatment	NH_4-N	NO_3-N	min-N
G1	Straw	- 3.4	-58.2	-61.6
	Grass	- 9.2	-57.0	-66.2
B1	Straw	- 9.4	-29.2	-38.6
	Grass	-17.8	-41.4	-59.2
R1	Straw	-40.2	11.2	-29.0
	Grass	88.1	-36.0	52.1

After 6 weeks incubation

G1	Straw	- 3.8	-50.1	-53.9
	Grass	- 9.1	-37.2	-46.3
B1	Straw	- 0.9	-45.1	-46.0
	Grass	-10.3	-34.8	-45.1
R1	Straw	-61.2	25.3	-35.9
	Grass	32.7	1.4	34.1

After 12 weeks incubation

G1	Straw	- 4.2	-44.8	-49.0
	Grass	- 9.0	-20.4	-29.4
B1	Straw	- 0.9	-45.9	-46.8
	Grass	-10.1	-27.4	-37.5
R1	Straw	-49.3	28.8	-20.5
	Grass	29.3	28.4	57.7

Negative values represent immobilization whilst positive values represent net mobilization.

TABLE 5D

Chap. 4 Expt. 4

CARBON DIOXIDE RELEASE AFTER EACH PERIOD OF INCUBATION FROM G1, B1 and R1 SOILS TREATED WITH 0.5% STRAW AND GRASS

(Results are given in ppm on dry soil basis)

Soil	Treatment	Weeks 0-2	2-6	0-6	6-12	0-12
G1	Control	1155	965	2120	980	3100
"	Straw	3710	2155	5865	2140	8005
"	Grass	4485	2190	6675	1900	8575
B1	Control	765	495	1260	875	2135
"	Straw	3910	1890	5800	1580	7380
"	Grass	4475	1815	6290	1565	7855
R1	Control	710	735	1445	1195	2640
"	Straw	2430	1420	3850	1015	4865
"	Grass	4425	1495	5920	1205	7125
	APPARENT CO_2 RELEASE FROM STRAW AND GRASS					
G1	Straw	2555	1190	3745	1160	4905
"	Grass	3330	1225	4555	920	5475
B1	Straw	3145	1395	4540	705	5245
"	Grass	3710	1320	5030	690	5720
R1	Straw	1720	685	2405	0	2405
"	Grass	3715	760	4475	10	4485

L.S.D ($P < 0.05$) 320

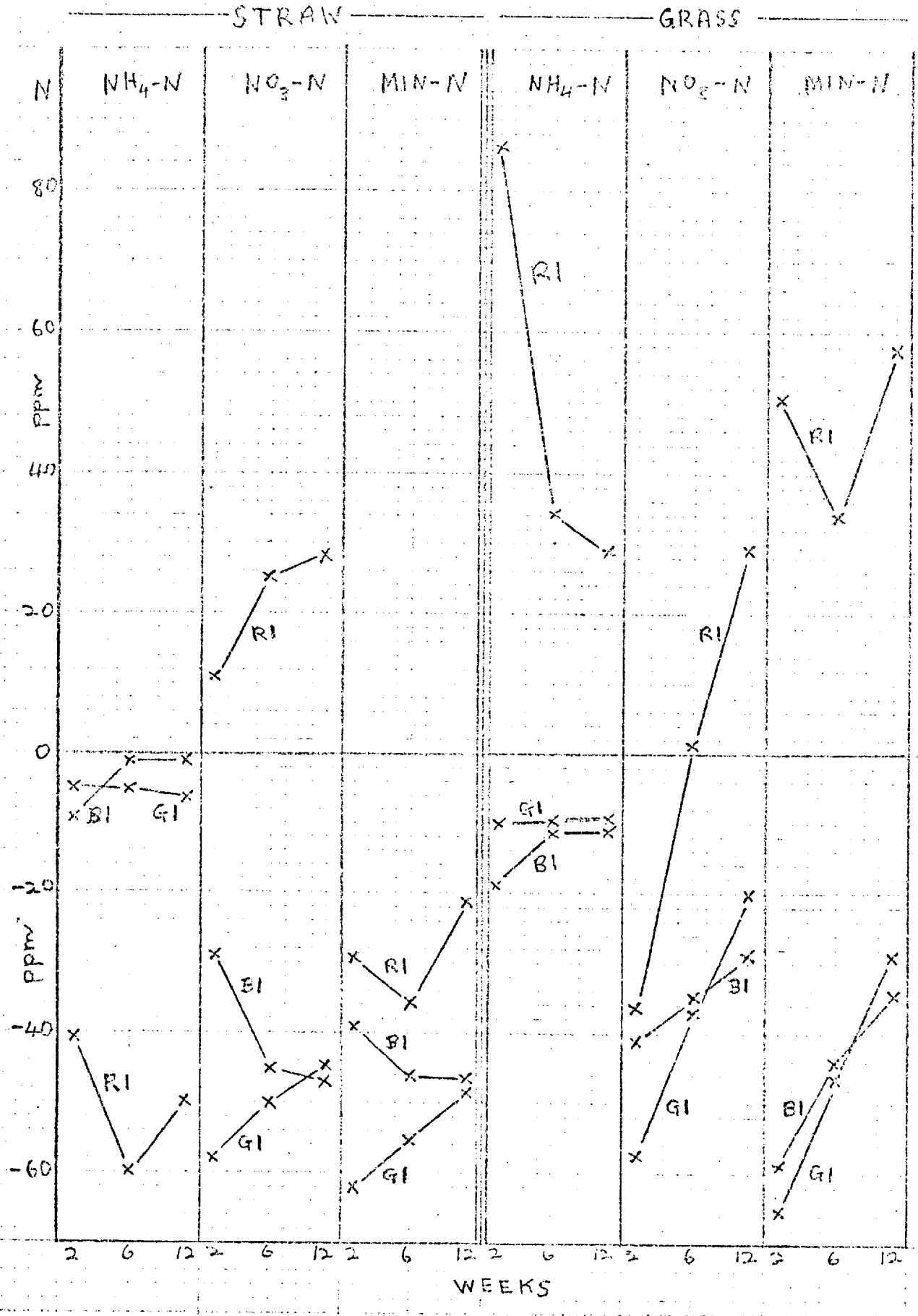
	% RECOVERY OF STRAW- AND GRASS-C AS CO_2					
G1	Straw	35.2	16.4	51.6	16.0	67.6
"	Grass	47.5	17.5	65.0	13.1	78.1
B1	Straw	43.3	19.2	62.5	9.7	72.2
"	Grass	53.0	18.8	71.8	9.9	81.7
R1	Straw	23.7	9.4	33.1	0	33.1
"	Grass	53.0	10.9	63.9	0.1	64.0

L.S.D. ($P < 0.05$) 8% CO_2

CHAPTER 4 Expt.4 Fig.1

Mineral N mobilization during incubation over 12 weeks of G1, B1 and R1 soils treated with 0.5% straw and grass.

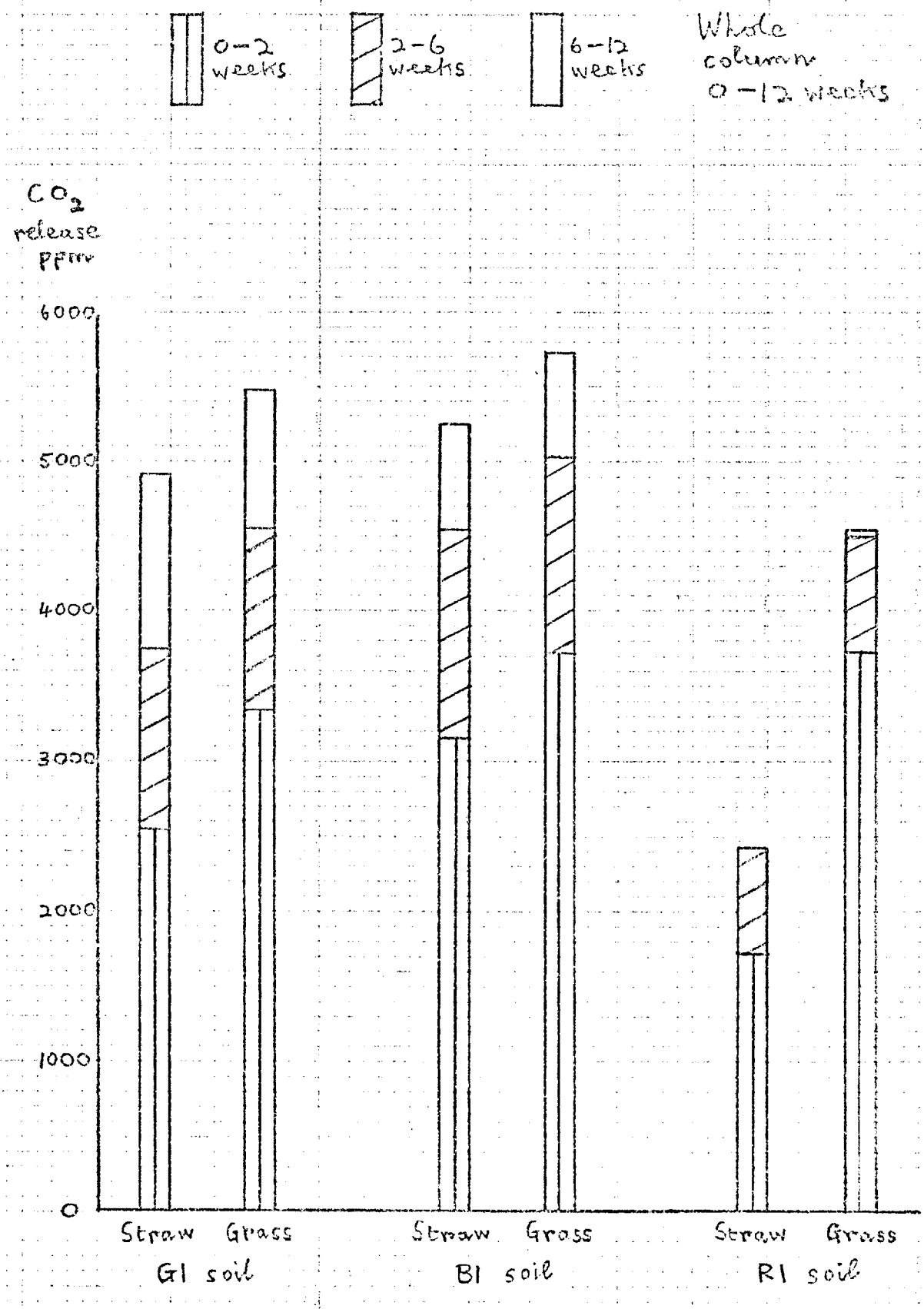
(All soils including controls received 100 ppm N as NH_4NO_3)



CHAPTER 4 Expt.4 Fig.2

Apparent carbon dioxide release from straw and grass during incubation over 12 weeks of G1, B1 and R1 soils treated with 0.5% straw and grass.

(All soils including controls received 100 ppm N as NH_4NO_3)



Nitrogen Changes

After 2 weeks immobilization of mineral N was about the same for straw and grass in the G1 soil. However, nitrate was immobilized to a much greater extent than was ammonium with both treatments. In the B1 soil immobilization due to grass was higher than that due to straw. Nitrate was immobilized to a greater extent than was ammonium. In the R1 soil there was moderate immobilization due to grass. With straw the immobilized mineral N was accounted for entirely as ammonium, and there was a small net mineralization of nitrate. With grass, on the other hand, the net mineralization of mineral N was accounted for entirely as ammonium and there was a fair amount of nitrate immobilization.

After 6 weeks the extent of immobilization of mineral N by straw and grass in the G1 soil was somewhat less than after 2 weeks. With both treatments the immobilization of mineral N was accounted for largely as nitrate, but the extent of the decrease was less than after 2 weeks, particularly with grass. In the B1 soil immobilized mineral N was greater after 6 than after 2 weeks with straw, but the reverse was true with grass. With straw immobilized mineral N was accounted for entirely as nitrate, whilst with grass both forms of mineral N were immobilized. In the R1 soil there was net immobilization of mineral N with straw, of the same order as after 2 weeks. With grass the net mineralization of N was less after 6 than after 2 weeks. With straw the immobilized mineral N was accounted for entirely as ammonium, whilst there was some net mineralization of nitrate. With grass the mineralized N was accounted for almost entirely as ammonium.

After 12 weeks immobilization of mineral N was greater by straw than by grass in the G1 soil. The immobilized N was accounted for almost entirely as nitrate where straw was added, but with grass immobilization of nitrate was about twice that of ammonium. In the B1 soil immobilization of mineral N was slightly greater due to straw than grass. The immobilized N was accounted for entirely as nitrate with straw, but with grass both forms of N were immobilized. In the R1 soil with straw there was net mineralization of nitrate, but the greater immobilization of ammonium resulted in net immobilization of mineral N. With grass there was net mineralization of both forms of N, with each contributing to about the same extent.

Carbon dioxide release

Table 5D shows (i) carbon dioxide release from the control and straw- and grass-treated soils, (ii) apparent carbon dioxide release from straw and grass obtained by subtracting values for control soils from treated soils (these results are also shown diagrammatically in Figure 2), (iii) the percent recovery of straw- and grass-carbon as carbon dioxide, calculated from the apparent carbon dioxide release from the added straw and grass of known carbon content; it was assumed (though this may not be strictly valid) that the addition of the organic materials did not affect the rate of carbon dioxide release from soil organic carbon.

After each main period (0-2, 0-6 and 0-12 weeks) carbon dioxide release from grass was considerably greater than from straw with the R1 than with the G1 and B1 soils. The differences in carbon dioxide release due to grass and straw for each soil occurred mainly during the 0-2 week period, since these differences were very similar for

each of the periods mentioned above. After each main period with the straw treatment carbon dioxide release decreased in the order B1, G1, R1. With the grass treatment over 0-2 weeks carbon dioxide release was similar and greater from the B1 and R1 soils than from the G1 soil. However during the 0-6 week period carbon dioxide release from the grass treatment was greater with the B1 than with the G1 and R1 soils, from which release was similar. Over 0-12 weeks carbon dioxide release decreased in the order B1, G1, R1. With the R1 soil most of the carbon dioxide released from straw and grass came off during the first 2 weeks. Moderate amounts were released during 2-6 weeks and nil or negligible amounts during 6-12 weeks. The percent recovery of straw- and grass-carbon as carbon dioxide over 12 weeks with both straw and grass additions decreased in the order B1, G1, R1. Percent recovery from straw in the R1 soil was particularly low.

In the G1 soil pH increased with incubation to 6-12 weeks irrespective of treatment. The B1 soil showed negligible changes in pH due to treatment or incubation. The pH of the R1 soil showed little change with incubation time where straw was added. With grass pH increased by one unit after 2 weeks, but returned approximately to the initial value by 6 and 12 weeks.

DISCUSSION

Nitrogen Changes

The G1 and B1 soils behaved similarly, but differently from the R1 soil with respect to the extent to which immobilized N was accounted for as ammonium or nitrate. In the G1 and B1 soils after all periods of incubation with straw or grass nitrate was immobilized

to a greater extent than was ammonium. With the straw-treated R1 soil, on the other hand, immobilized N was accounted for entirely as ammonium after all periods. With grass-treated R1 soil only nitrate was immobilized, but only up to 2 weeks and nitrate accumulated with further incubation. There was net mineralization of N after all periods due entirely to ammonium after 2 and 6 weeks and to both ammonium and nitrate after 12 weeks. The relatively low pH of the R1 soil could account for the accumulation of ammonium with the grass treatment, since autotrophic nitrification would be low or absent. Since grass decomposed much more rapidly than did straw and, because of the high N content of the grass and low pH of the R1 soil, the mineralized N would tend to accumulate as ammonium in the early stages of incubation. This is confirmed by the increased pH during the first two weeks of incubation. With further incubation net ammonium levels decreased due to nitrification and this was accompanied by the expected fall in pH.

The possibility of occurrence of heterotrophic nitrification in the R1 soil with both straw and grass must be considered. With straw net nitrate mineralization occurred during 0-2 weeks and increased with further incubation, whilst with grass there was no net nitrification until the 6-12 week period. It is likely that because of the vigorous decomposition of grass compared with that of straw during early incubation that conditions were not suitable for heterotrophic nitrification because of the high accumulation of ammonium. With straw on the other hand there was no net accumulation of ammonium at any stage and hence no inhibition of nitrification even during the early stages. Ishaque (21) found in a Bangladesh "Tea" soil of pH 4.2 that nitrification occurred when the soil was incubated

without addition of anything, but was very low when ammonium sulphate was added. It has been shown (50, 51) that strains of Aspergillus flavus and Penicillium species were able to convert some organic nitrogenous compounds to nitrate in culture tests. Since these organisms are widely distributed in soils it is likely that heterotrophic nitrification can occur in some soils due to their activity. It is possible that straw and grass and some of their degraded organic nitrogenous compounds may be suitable substrates for heterotrophic nitrification.

The properties of the G1 and B1 soils with respect to the levels of mineral N forms during incubation with the added organic materials were essentially similar for both straw and grass. There was no net mineralization of either form of N. The only difference between G1 and B1, which occurred only with straw, was the greater immobilization of nitrate by G1 during 0-2 weeks. This suggests that the microorganisms attacking straw were more vigorous in G1 than in B1 and that they preferred nitrate over ammonium as their mineral N source. In the R1 soil on the other hand there was net mineralization of ammonium and nitrate after all periods of incubation where grass was added, whilst with straw only nitrate accumulated. This is likely to be due to the greater mineralization of N from grass (containing 3.53% total N) than from straw (0.68% N), and the preference by the immobilizing microorganisms for ammonium over nitrate. The much more rapid decomposition of grass than of straw is confirmed by the higher carbon dioxide release with the former treatment.

DISCUSSION

Carbon dioxide release

After all periods of incubation with all three soils with both

straw and grass treatments, mineral N levels were not limiting the decomposition of added organic materials.

Carbon dioxide release from the control G1 soil was greater than that from the control B1 soil over 12 weeks of incubation. However, where the organic materials were added the apparent release of carbon dioxide from both materials was somewhat higher from B1 than from G1. This suggests some difference in the nature of the two soils with respect to microbiological activity, with the B1 soil being more active than the G1 in decomposing added organic materials. The relatively small differences in decomposition between straw and grass in the B1 and G1 soils differs from results obtained with English soils of the same pH (245), where the rate of grass decomposition, as measured by apparent carbon dioxide release, was twice that of straw. With the R1 soil, on the other hand, carbon dioxide release from grass was twice that from straw. Because of the low pH (4.4-4.7) after 6 and 12 weeks of incubation of the R1 soil, it is likely that fungi rather than bacteria were responsible for decomposition (1). On the other hand, with the G1 and B1 soils, with pH ranging from 6.8-8.0, it was more likely that bacterial rather than fungal activity was responsible for carbon mineralization.

The virtual apparent absence of carbon dioxide release from straw and grass in the R1 soil over 6-12 weeks may have been due to the production of a toxic material(s) earlier in incubation which inhibited further decomposition of straw and grass. It is worth noting that mineral N which accumulated during 6-12 weeks with the R1 soil treated with grass did so largely as nitrate, and the nitrification processes (whether autotrophic or heterotrophic) were not inhibited. The material(s) toxic to carbon dioxide release must

have been a metabolic product of grass and straw rather than a metabolic product of soil organic matter decomposition, since carbon dioxide release from the R1 soil receiving no treatment was fairly high during 6-12 weeks. Alternatively, some essential nutrient other than N may have become limiting to the microorganisms responsible for grass and straw decomposition during the 6-12 week period in the R1 soil.

SUMMARY OF CHAPTER 4

The effects of adding 0.5% ground straw and grass (plus 100 ppm N as ammonium nitrate to all including control soils) on mineral N changes and carbon dioxide release over 12 weeks of incubation (30^{o} and 50% saturation) of G1, B1 and R1 soils were studied.

In the G1 soil immobilization of mineral N was at a maximum with both straw and grass after 2 weeks, but decreased after 6 and 12 weeks. In the B1 soil immobilization after 2 weeks was greater with grass than with straw. After 6 and 12 weeks immobilization due to straw increased slightly, whilst that due to grass decreased somewhat. In the R1 soil immobilization due to straw increased up to 6 weeks and decreased to 12 weeks. With the grass treatment there was net mineralization of N after all periods, with the lowest level after 6 weeks. In all soils after 12 weeks straw caused more immobilization of N than did grass. Immobilization due to straw was twice as great in the G1 and B1 soils than in R1.

In the G1 and B1 soils immobilization of N due to straw was accounted for almost entirely or largely as nitrate after all periods. With grass nitrate accounted for most of the mineral N immobilized. In the R1 soil with straw immobilization was accounted for entirely as ammonium after all periods, and there was net mineralization of nitrate, particularly after 12 weeks. With grass there was net immobilization of nitrate after 2 weeks, but net mineralization as nitrate after 12 weeks.

By 12 weeks of incubation the apparent recovery of carbon as carbon dioxide from the added organic materials was greater for grass than for straw, particularly with the R1 soil. Recovery of

carbon dioxide from straw was about the same for G1 and B1 soils, being about twice that from the R1 soil. Recovery of carbon dioxide from grass was about the same with the G1 and B1 soils, whilst that from the R1 soil was somewhat lower. There was virtually no apparent recovery of straw or grass carbon as carbon dioxide from the R1 soil during the 6-12 week period.

CHAPTER 5

EFFECTS OF ALTERING SOIL pH ON MINERAL NITROGEN CHANGES DURING INCUBATION OF G2, B2 AND R2 SOILS WITHOUT AND WITH ADDITION OF AMMONIUM SULPHATE

Experiment 5

Effects of varying levels of sulphur on mineral nitrogen changes during incubation over 13 weeks of G2 soil without and with addition of ammonium sulphate.

Experiment 6

Effects of varying levels of sulphur on mineral nitrogen changes during incubation over 13 weeks of B2 soil without and with addition of ammonium sulphate.

Experiment 7

Effects of 0.1% sulphur and varying levels of calcium carbonate on mineral nitrogen changes during incubation over 13 weeks of R2 soil without and with addition of ammonium sulphate.

CHAPTER 5

EFFECTS OF ALTERING SOIL pH ON MINERAL NITROGEN CHANGES DURING INCUBATION OF G2, B2 and R2 SOILS WITHOUT AND WITH ADDITION OF AMMONIUM SULPHATE

The experiments described in this chapter were done to determine to what extent N mineralization and nitrification were affected by altering soil pH. The G2 soil (pH 7.9 and containing 6.0% calcium carbonate) was treated with varying levels of powdered sulphur up to 1.0% The B2 soil (pH 7.8 and containing 0.3% calcium carbonate) was treated with sulphur levels up to 0.2%. The R2 soil (pH 5.1) was treated with one level of sulphur (0.1%) and with calcium carbonate levels up to 0.6%. Sulphur is commonly used to decrease soil pH, e.g., to decrease the susceptibility of potatoes to scab (Streptomyces scabies) and rot (S. ipomoeae) diseases (1), and also for reclaiming alkali soils (247). The acidifying effect of sulphur relies on the activity of microorganisms which oxidize sulphur to sulphate (sulphuric acid). The microorganisms involved are the obligate aerobes Thiobacillus thiooxidans and T. thioparus and the facultative anaerobe T. denitrificans (246).

EXPERIMENT 5

Effects of varying levels of sulphur on mineral nitrogen changes during incubation over 13 weeks of G2 soil without and with addition of ammonium sulphate.

METHODS

Finely ground sulphur (< 0.25 mm) at levels of 0.1, 0.2, 0.5 and 1.0% were mixed with four lots of G2 soil. Half of each of these soils were mixed with finely ground ammonium sulphate to supply 100 ppm added N. These soils as well as suitable controls (without added sulphur or N and with added N only) were set up for incubation at 30° and 50% saturation. The soils were analysed for mineral N initially and after 6 and 13 weeks of incubation.

RESULTS

Table 6 presents mineral N levels and accumulation values. Figure 3 presents accumulation values. Negative accumulation values indicate less mineral N after incubation than initially.

Where no ammonium sulphate was added nitrate accumulation decreased with increasing level of S until with 1% S there was no nitrate accumulation; in fact there was slight loss of nitrate. The only significant, though small, accumulation of ammonium occurred only after 13 weeks with 1% S.

Where ammonium sulphate was added about 75% of the added ammonium was fixed initially. Nitrate accumulation to 6 weeks decreased with increasing S level up to 0.2% and there was no nitrate accumulation with the higher S levels; in fact there was some loss of nitrate. However, over 6-13 weeks nitrate accumulation with 0.2% was considerably greater than with 0.1% S, so that by the end of incubation nitrate

TABLE 6

Chap. 5 Expt. 5

MINERAL-N LEVELS AND ACCUMULATION DURING INCUBATION (6 and 13 weeks) OF G2 SOIL (calcereous) WITHOUT AND WITH ADDITION OF 100 ppm N AS AMMONIUM SULPHATE AND DIFFERENT LEVELS OF SULPHUR (0.1% - 1.0%)

(Results are given in ppm on dry soil basis)
N = 100 ppm N as ammonium sulphate

Initial values

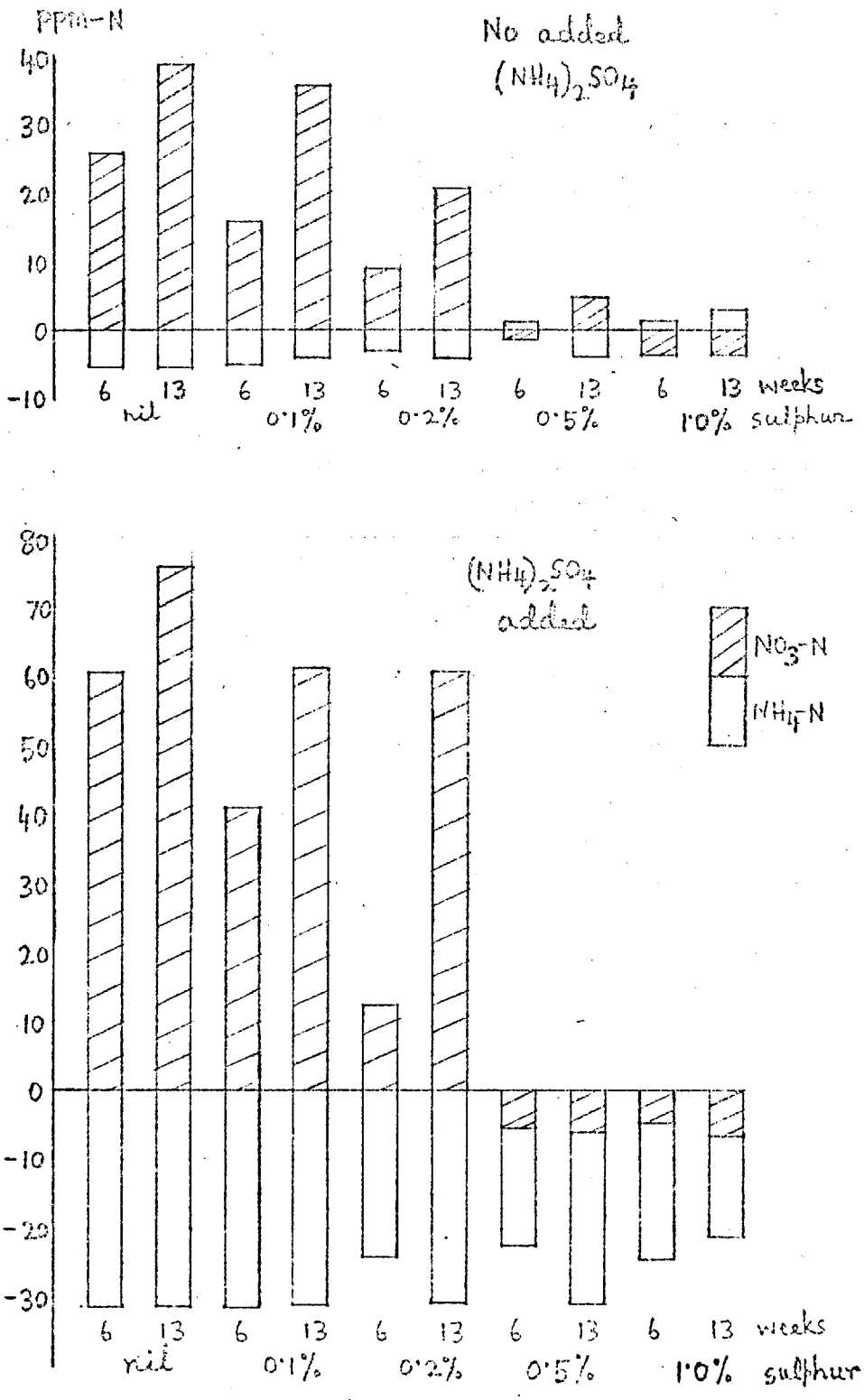
Treatment	NH_4-N	NO_3-N	min-N	pH
0	5.9	6.4	12.3	8.0
N	32.5	7.8	40.3	7.8

	L E V E L S				ACCUMULATION		
	After 6 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	0.7	31.9	32.6	8.3	- 5.2	25.5	20.3
N	1.3	68.4	69.7	8.2	-31.2	60.6	29.4
0.1% S	1.0	22.1	23.1	8.2	- 4.9	15.7	10.8
0.1% S+N	1.1	48.7	49.8	8.1	-31.4	40.9	9.5
0.2% S	3.0	15.2	18.2	7.9	- 2.9	8.8	5.9
0.2% S+N	8.6	20.3	28.9	7.8	-23.9	12.5	-11.4
0.5% S	7.0	5.3	12.3	7.8	1.1	-1.1	0
0.5% S+N	15.4	2.6	18.0	7.8	-17.1	-5.2	-22.3
1.0% S	7.0	3.1	10.1	7.8	1.1	-3.3	- 2.2
1.0% S+N	12.9	3.3	16.2	7.8	-19.6	-4.5	-24.1
	After 13 weeks incubation						
0	0.8	44.8	45.6	8.3	- 5.1	38.4	33.3
N	1.3	83.6	84.9	8.1	-31.2	75.8	44.6
0.1% S	2.0	41.7	43.7	8.1	- 3.9	35.3	31.4
0.1% S+N	1.6	69.0	70.6	8.0	-30.9	61.2	30.3
0.2% S	2.0	27.0	29.0	7.9	- 3.9	20.6	16.7
0.2% S+N	1.8	68.4	70.2	7.9	-30.7	60.6	29.9
0.5% S	2.2	11.2	13.4	8.0	- 3.7	4.8	1.1
0.5% S+N	7.6	1.9	9.5	8.0	-24.9	-5.9	-30.8
1.0% S	9.0	3.1	12.1	8.1	3.1	-3.3	- 0.2
1.0% S+N	18.0	1.3	19.3	7.9	-14.5	-6.5	-21.0

L.S.D ($P < 0.05$) NH_4-N 1.3, NO_3-N 2.5, min-N 2.9

CHAPTER 5 Expt.5 Fig.3 G2soil

Effects of varying levels of sulphur on mineral N accumulation during incubation over 13 weeks of G2 soil without and with addition of ammonium sulphate (100 ppm N).



levels were the same with both these S levels, but somewhat lower than in the control. With 0.5 and 1.0% S nitrate loss after 13 weeks was the same as after 6 weeks. With the two higher levels of S there was less loss of ammonium than with the other treatments by 13 weeks.

The level of pH values due to treatments with S decreased by a maximum of 0.5 units over 6-13 weeks. The minimum pH with any of the treatments was 7.8.

DISCUSSION

Even with the highest level of S (1.0%) it was calculated that even if this had been completely oxidised to sulphuric acid over 13 weeks, only half of the calcium carbonate present would have been neutralized. This accounts for the relatively small decreases in pH. Within the pH range obtained (7.8-8.3) it is unlikely that N changes would be affected by pH. The general decrease in N mineralization and nitrification with increasing level of S was probably due to the temporary acidity produced in the vicinity of each S particle as it was oxidized to sulphuric acid. This would cause a decrease in the activity of nitrifying organisms in particular. However the fact that with up to 0.2% S mineralized N accumulated entirely as nitrate suggests that nitrification may have been limited by nitrogen mineralization.

Initially about three quarters of the added ammonium was fixed by the soil in non-exchangeable form. In the control soil 60% fixation occurred by 13 weeks, suggesting that there was some nitrification of fixed ammonium. With 0.2% S there was no nitrification of fixed ammonium up to 6 weeks but by 13 weeks about 40% of the ammonium was nitrified, with 25% from exchangeable ammonium and 15% from fixed ammonium. This suggests that all the added 0.2% S was oxidized during

the first 6 weeks, causing decreased nitrification. However, during 6-13 weeks the localized acidity was neutralized by the excess calcium carbonate and the nitrifying organisms increased their activity and were able to nitrify some of the fixed ammonium. With 0.5 and 0.1% S localized acidity due to S particles must have persisted through the whole 13 weeks, resulting in virtually no nitrification of either exchangeable or fixed ammonium.

The loss of nitrate and ammonium with 0.5 and 1.0% S, particularly after 13 weeks, was probably accounted for by immobilization due to the localized acidity produced by these high S levels. It is likely that the acidity encouraged decomposition of organic N compounds by heterotrophs and also by chemical action and the heterotrophs utilized the mineral N forms as they attacked organic materials.

EXPERIMENT 6

Effects of varying levels of sulphur on mineral nitrogen changes during incubation over 13 weeks of B2 soil without and with addition of ammonium sulphate.

METHODS

Two lots of original B2 soil were mixed with 0.1% and 0.2% S. Half of each of these soils as well as a control soil were mixed with finely ground ammonium sulphate to supply 100 ppm added N. These soils as well as suitable controls (without added S or N and with added N only) were set up for incubation at 30^{o} and 50% saturation. The soils were analysed for mineral N initially and after 6 and 13 weeks of incubation.

RESULTS

Table 7 shows the levels and accumulation of mineral N, and accumulation values are also shown in Figure 4.

Where no ammonium sulphate was added nitrate accumulation decreased with increasing S level after both 6 and 13 weeks. There was no ammonium accumulation with the nil and 0.1% S treatments, but small accumulation with 0.2% S. Nitrate accumulation increased somewhat during the 6-13 week period with the nil and 0.1% S treatments, but not with 0.2% S.

Where ammonium sulphate was added only about half the added ammonium was recovered initially by potassium chloride extraction, indicating that about half the added ammonium had been fixed. Nitrate accumulation decreased considerably with increasing S level after both 6 and 13 weeks. The rate of decrease with increasing level of S was much greater than where no ammonium sulphate was added. In fact after 6 weeks with 0.2% S, there was no nitrate accumulation, although a

TABLE 7

Chap. 5 Expt. 6

MINERAL-N LEVELS AND ACCUMULATION DURING INCUBATION (6 and 13 weeks) OF B2 SOIL WITHOUT AND WITH ADDITION OF 100 ppm N AS AMMONIUM SULPHATE AND DIFFERENT LEVELS OF SULPHUR

(Results are given in ppm on dry soil basis)

N = 100 ppm N as ammonium sulphate.

Initial values

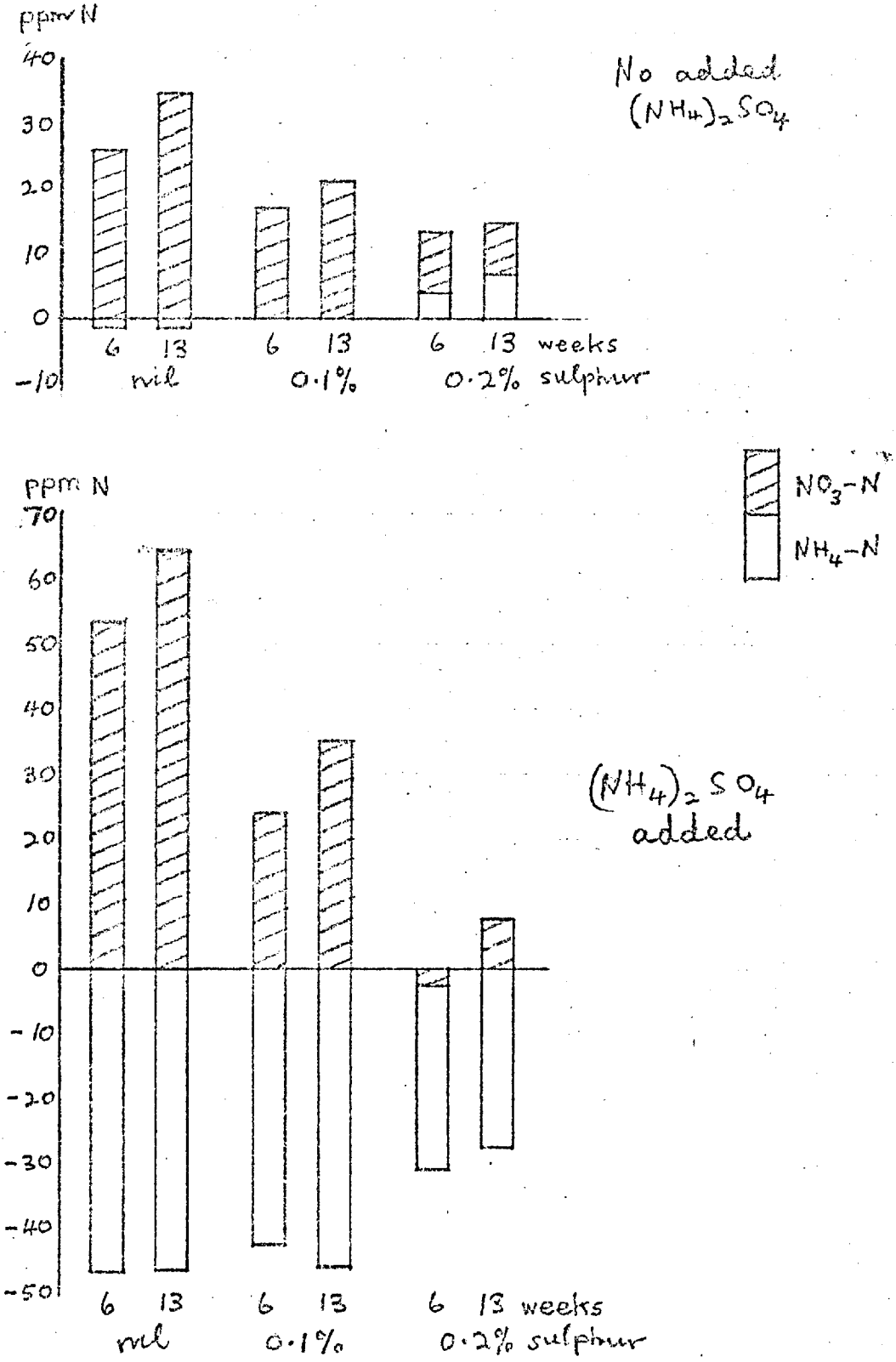
Treatment	NH_4-N	NO_3-N	min-N	pH
0	2.0	3.4	5.4	7.8
N	47.1	6.8	53.9	7.5

	L E V E L S				ACCUMULATION		
	After 6 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	0.9	29.1	30.0	8.1	- 1.1	25.7	24.6
N	1.4	60.2	61.6	7.8	-45.7	53.4	7.7
0.1% S	2.3	20.2	22.5	7.0	0.3	16.8	17.1
0.1% S+N	4.5	30.8	35.3	6.8	-42.6	24.0	-18.6
0.2% S	5.9	12.6	18.5	6.6	3.9	9.2	13.1
0.2% S+N	18.7	4.6	23.3	6.5	-28.4	-2.2	-30.6
	After 13 weeks incubation						
0	0.9	37.8	38.7	8.0	- 1.1	34.4	33.3
N	1.3	71.0	72.3	7.8	-45.8	64.2	18.4
0.1% S	1.4	24.4	25.8	7.0	- 0.6	21.0	20.4
0.1% S+N	1.2	41.8	43.0	6.8	-45.9	35.0	-10.9
0.2% S	8.7	11.0	19.7	6.4	6.7	7.6	14.3
0.2% S+N	19.9	14.0	33.9	6.3	-27.2	7.2	-20.0

L.S.D ($P < 0.05$) NH_4-N 1.5, NO_3-N 1.7 and min-N 2.0

CHAPTER 5 Expt.6 Fig.4 B2 soil

Effects of varying levels of sulpur on mineral N accumulation during incubation over 13 weeks of B2 soil without and with addition of ammonium sulphate (100 ppm N).



little accumulated after 13 weeks. About one-third of the applied ammonium was recovered as nitrate with the control soil after 6 and 13 weeks, but only about 10% with the 0.1% S treatment. There was no recovery of applied ammonium with 0.2% S after 6 or 13 weeks.

Whether or not ammonium sulphate was applied, pH decreased by about one unit, compared with the control, where 0.1% S was applied and by about 1.5 units where 0.2% was applied. Where ammonium sulphate was applied pH was slightly lower (0.1-0.3 unit) than where no ammonium sulphate was applied.

DISCUSSION

In this soil it was calculated that even the lower level of applied S (0.1%) was sufficient to neutralize all the calcium carbonate present. This was confirmed by the reduction in pH of one unit with 0.1% S and by 1.5 units with 0.2% S. Thus decreasing nitrification with increasing level of S may have been due partly to decrease in pH. However, immobilization may also have accounted partly for the lower nitrate with the S treatments as described with the G2 soil. Comparison of the G2 and B2 soils showed that the rate of decrease of nitrification with increasing S level up to 0.2% was about the same where no ammonium sulphate was applied, but was considerably greater in B2 than in G2 where ammonium sulphate was applied. There was apparently very little nitrification of fixed ammonium during the 6-13 week period in the B2 soil with 0.1 and 0.2% S compared with that obtained with the G2 soil at the same levels of S.

EXPERIMENT 7

Effects of adding 0.1% sulphur and 0.3% and 0.6% calcium carbonate on mineral nitrogen changes during incubation over 13 weeks of R2 soil without and with addition of ammonium sulphate.

METHODS

One lot of original R2 soil was mixed with 0.1% S and two other lots with 0.3% and 0.6% $CaCO_3$. Half of each of these lots as well as control soil were mixed with ammonium sulphate to supply 100 ppm added N. These soils as well as suitable controls (without added S or N and with added N only) were set up for incubation at 30° and 50% saturation. The soils were analysed for mineral N initially and after 6 and 13 weeks of incubation.

RESULTS

Table 8 presents results for mineral N levels and accumulation values. Fig. 5 shows accumulation values. Negative accumulation values indicate less mineral N after incubation than initially.

Where no ammonium sulphate was added there was moderate accumulation of nitrate in the control soil. With 0.1% S mineralized N accumulated entirely as ammonium after 6 and 13 weeks of incubation. With increasing level of $CaCO_3$ there was a moderate increase in mineralized N, which accumulated entirely as nitrate. There was some decrease in ammonium accumulation with all treatments except 0.1% S, where there was slight loss of nitrate.

Where ammonium sulphate was added nitrate accumulation in the control soil (no S or $CaCO_3$ added) was slightly lower than where no ammonium sulphate was added. With 0.1% S nitrification was inhibited but there was some accumulation of ammonium. With $CaCO_3$ additions

TABLE 8

Chap. 5 Expt. 7

LEVELS AND ACCUMULATION OF MINERAL-N DURING INCUBATION (6 and 13 WEEKS) OF R2 SOIL WITHOUT AND WITH ADDITION OF 100 ppm N AS AMMONIUM SULPHATE AND 0.1% SULPHUR AND 0.3 AND 0.6% CALCIUM CARBONATE

(Results are given in ppm on dry soil basis)

N = 100 ppm N as ammonium sulphate.

Initial values

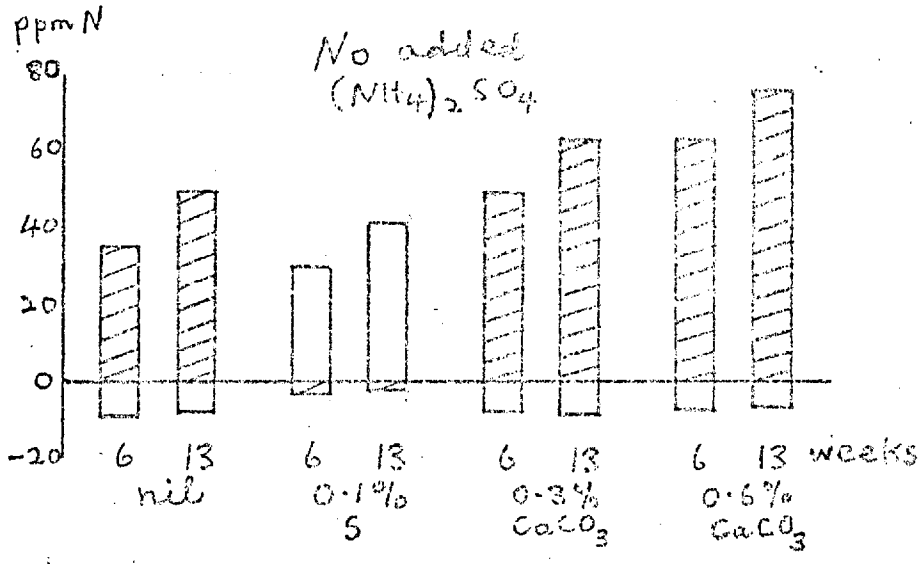
Treatment	NH_4-N	NO_3-N	min-N	pH
0	12.1	3.9	16.0	5.0
N	104.2	3.9	108.1	4.8

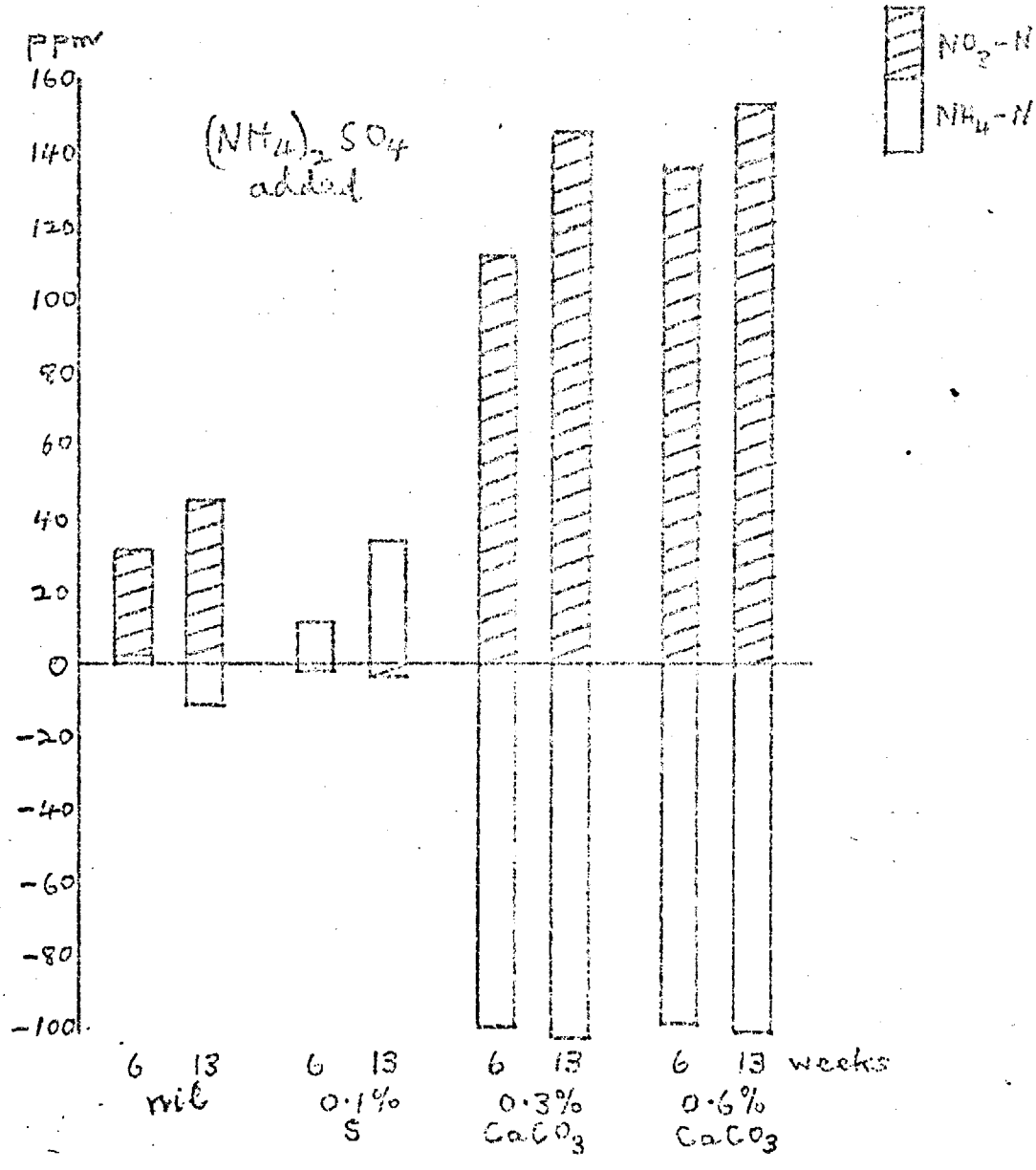
	L E V E L S				ACCUMULATION		
	After 6 weeks incubation						
Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	2.3	38.7	41.0	4.4	- 9.8	34.7	24.9
N	106.4	36.4	142.8	4.5	2.2	28.6	30.8
0.1% S	41.2	1.3	42.5	4.3	29.1	-2.7	26.4
0.1% S+N	115.4	3.3	118.7	4.3	11.2	-0.6	10.6
0.3%$CaCO_3$	4.0	52.4	56.4	6.8	- 8.1	48.4	40.3
0.3%$CaCO_3$+N	4.8	118.5	123.3	6.4	-99.4	114.6	15.2
0.6%$CaCO_3$	5.5	66.9	72.4	7.9	- 6.6	63.0	56.4
0.6%$CaCO_3$+N	5.7	141.3	147.0	7.5	-98.5	137.4	38.9
	After 13 weeks incubation						
0	2.4	53.3	55.7	4.2	- 9.7	49.4	39.7
N	94.1	48.1	142.2	4.3	-10.1	44.2	34.1
0.1% S	52.5	1.3	53.8	4.0	40.4	- 2.6	37.8
0.1%S+N	138.1	0.6	138.7	4.1	33.9	- 3.3	30.6
0.3%$CaCO_3$	3.1	66.9	70.0	6.5	- 9.0	63.0	54.0
0.3%$CaCO_3$+N	2.4	149.9	152.3	6.2	-101.8	146.0	44.2
0.6%$CaCO_3$	5.8	79.9	85.7	7.9	-6.3	76.0	69.7
0.6%$CaCO_3$+N	5.6	158.2	163.8	7.7	-98.6	154.3	55.7

L.S.D ($P < 0.5$) NH_4-N 2.0, NO_3-N 3.0 and min-N 3.3

CHAPTER 5 Expt.7 Fig.5 R2 soil

Effects of addition of sulphur and varying levels of calcium carbonate on mineral N accumulation during incubation over 13 weeks of R2 soil without and with addition of ammonium sulphate (100 ppm N).





there was considerable nitrate accumulation to 6 weeks and somewhat more to 13 weeks. There were considerable decreases in ammonium with both $CaCO_3$ levels. Fixation of added ammonium initially by the R2 soil was considerably less than by G2 and B2 soils. R2 fixed 8%, G2 74% and B2 55% of the added ammonium.

The S treatment decreased soil pH by 0.1-0.2 units compared with the control soils by 13 weeks. Where 0.3% $CaCO_3$ was added pH was increased by 1.9-2.4 units, and with 0.6% $CaCO_3$ by 2.9-3.4 units.

DISCUSSION

The absence of nitrification where 0.1% S was added compared with the control indicates that nitrification was heterotrophic rather than autotrophic, since the very small decrease in pH (0.1-0.2 units) due to the S treatment would hardly have further inhibited autotrophic nitrification. The possibility that an acid-adapted strain of an autotrophic nitrifier may have been operative must also be considered. However, this is unlikely, since where ammonium sulphate was added no extra nitrate was produced over that occurring in the control soil. In this respect the R2 soil differed from the G2 and B2 soils, where nitrification was increased by addition of ammonium sulphate, suggesting that autotrophic nitrification was operative. Ishaque (21) found in an incubation study of a Bangladesh "Tea" soil of pH 4.2 that ammonium sulphate addition stopped nitrification whereas organic nitrogen sources (urea, oxamide and dried blood) increased nitrification over the control. Etinger-Tulczynska (14) obtained similar results with Israeli soils of pH 7.7-8.), in which evidence was presented that a heterotrophic process was responsible for nitrification.

The considerably increased nitrification in R2 due to ammonium sulphate addition with both levels of $CaCO_3$ is more likely due to autotrophic nitrification, since the extra nitrate produced above that in the controls (no ammonium sulphate added) accounted for 60-80% of the decrease in ammonium.

SUMMARY OF CHAPTER 5

Experiment 5

The effects of addition of varying levels of sulphur (0.1, 0.2, 0.5 and 1.0%) on mineral N changes during incubation (30° and 50% saturation) over 13 weeks of G2 soil (pH 7.9, 6.0% calcium carbonate) without and with addition of ammonium sulphate (100 ppm N) were studied. Where no ammonium sulphate was added nitrification and N mineralization decreased with increasing S level and both processes were stopped by 0.5 and 1.0% S. Where ammonium sulphate was added about 75% of the added ammonium was fixed initially. Nitrate accumulation to 6 weeks decreased with increasing S level up to 0.2% and was stopped by higher S levels. By 6 weeks nitrate accumulation was greater with 0.1% S than with 0.2% S, but by 13 weeks accumulation was the same with both these S levels. By 13 weeks with 0.5 and 1.0% S there were net decreases in nitrate and ammonium.

Experiment 6

The effects of adding S (0.1 and 0.2%) on mineral N changes during incubation (30° and 50% saturation) over 13 weeks of B2 soil (pH 7.8, 0.3% calcium carbonate) without and with addition of ammonium sulphate (100 ppm N) were studied. Where no ammonium sulphate was added nitrification decreased with increasing S level and ammonium accumulated only with 0.2% S. Where ammonium sulphate was added 55% of the added ammonium was fixed initially. Nitrification decreased considerably with increasing S level. With 0.2% S there was slight loss of nitrate after 6 weeks, but some accumulation after 13 weeks. Loss of ammonium was not affected by 0.1% S but was decreased by 0.2% S.

Experiment 7

The effects of adding 0.1% S and calcium carbonate (0.3 and 0.6%) on mineral N changes during incubation (30° and 50% saturation) over 13 weeks of R2 soil (pH 5.1) without and with addition of ammonium sulphate (100 ppm N) were studied. Where no ammonium sulphate was added nitrification was stopped by 0.1% S but was increased considerably by both levels of calcium carbonate. Where ammonium sulphate was added about 8% of the added ammonium was fixed initially. Nitrification was stopped by 0.1% S and there was moderate accumulation of ammonium. With both calcium carbonate levels there was considerable nitrate accumulation and considerable decrease in ammonium. Results are discussed in relation to the likely occurrence of heterotrophic nitrification in this soil.

CHAPTER 6

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 12 WEEKS OF G1, B1 AND R1 SOILS TREATED WITH DRIED BLOOD AND HOOF AND HORN

CHAPTER 6

EXPERIMENT 8

Mineral nitrogen changes and carbon dioxide release during incubation to 12 weeks of G1, B1 and R1 soils treated with dried blood and hoof and horn (100 ppm nitrogen)

METHODS

Bulk samples of G1, B1 and R1 soils were mixed with finely ground (less than 0.25 mm) dried blood (DB; 13.0% N, 40.9% C) and hoof and horn (HH; 11.9% N, 40.1% C) to supply 100 ppm added N. Control and treated soils were set up for incubation at 30^{o} and 50% saturation. Mineral N was determined initially and after 3, 6 and 12 weeks of incubation. Carbon dioxide release was determined throughout incubation.

RESULTS

Table 9A shows mineral N levels and Table 9B mineral N accumulation after 3, 6 and 12 weeks. Table 9C shows the apparent mineral N accumulation due to DB and HH, obtained by subtracting values in the control soils from those in the treated soils. Table 9D shows CO_2 release from the control and treated soils and Table 9E shows apparent release of CO_2 from dried blood and hoof and horn.

Nitrogen Changes

After 3 weeks incubation mineral N accumulated almost entirely as nitrate in the control and treated G1 soils. In B1 and R1 there was less nitrate accumulation in the treated than in the control soils, and mineral N accumulated as nitrate and ammonium. After 6 weeks G1 and B1 behaved similarly in that mineralized N accumulated entirely as nitrate whilst ammonium decreased in the control and treated soils. In R1 in the control soil there was a moderate increase

CHAPTER 6

EXPERIMENT 8

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 12 WEEKS OF G1, B1 AND R1 SOILS TREATED WITH 100 ppm N AS DRIED BLOOD (DB) AND HOOF AND HORN (HH)

TABLE 9A
MINERAL NITROGEN LEVELS

(Results are in ppm on dry soil basis)

		Initial				3 weeks incubation			
Soil	Treatment	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N	pH
G1	C	6.0	13.4	19.4	7.4	0.5	39.0	39.5	7.7
"	DB	5.7	14.0	19.7	7.4	8.5	41.9	50.4	7.8
"	HH	8.0	14.2	22.2	7.5	6.7	37.5	44.2	7.8
B1	C	4.1	6.0	10.1	7.2	0.5	35.1	35.6	7.0
"	DB	3.7	6.4	10.1	7.1	16.8	20.5	37.3	7.1
"	HH	6.0	7.6	13.6	7.1	19.6	22.4	42.0	7.1
R1	C	10.4	5.4	15.8	5.2	4.0	31.3	35.3	4.8
"	DB	10.4	6.5	16.9	5.2	49.6	18.3	67.9	4.9
"	HH	11.2	7.0	18.2	5.2	49.8	17.7	67.5	5.0

C = control

		6 weeks incubation				12 weeks incubation			
G1	C	0	44.8	44.8	7.9	0	55.2	55.2	8.0
"	DB	0	74.2	74.2	8.0	0	99.7	99.7	8.0
"	HH	0.6	69.5	70.1	7.9	0.3	105.6	105.9	8.0
B1	C	0	40.7	40.7	7.0	0	47.6	47.6	7.1
"	DB	0.6	46.0	46.6	6.9	0	97.4	97.4	6.9
"	HH	0.4	65.1	65.5	6.8	0.3	99.2	99.5	6.9
R1	C	2.0	38.4	40.4	4.8	0	47.9	47.9	4.6
"	DB	21.3	65.1	86.4	4.6	18.2	88.2	106.4	4.4
"	HH	21.8	61.6	83.4	4.6	15.4	79.8	95.2	4.4

L.S.D ($P < 0.05$) NH_4-N 2.0, NO_3-N 3.1, min-N 3.5

TABLE 9B

MINERAL NITROGEN ACCUMULATION

Soil	Treatment	3 weeks incubation NH_4-N	NO_3-N	min-N	6 weeks incubation NH_4-N	NO_3-N	min-N
G1	C	- 5.5	25.6	20.1	- 6.0	31.4	25.4
"	DB	2.8	27.9	30.7	- 5.7	60.2	54.5
"	HH	- 1.3	23.3	22.0	- 7.4	55.3	47.9
B1	C	- 3.6	29.1	25.5	- 4.1	34.7	30.6
"	DB	13.1	14.1	27.2	- 3.1	39.6	36.5
"	HH	13.6	14.8	28.4	- 5.6	57.5	51.9
R1	C	- 6.4	25.9	19.5	- 8.4	33.0	24.6
"	DB	39.2	11.8	51.0	10.9	58.6	69.5
"	HH	38.6	10.7	49.3	10.6	54.6	65.2

		12 weeks incubation		
G1	C	- 6.0	41.8	35.8
"	DB	- 5.7	85.7	80.0
"	HH	- 7.7	91.4	83.7
B1	C	- 4.1	41.6	37.5
"	DB	- 3.7	91.0	87.3
"	HH	- 5.7	91.6	85.9
R1	C	-10.4	42.5	32.1
"	DB	7.8	81.7	89.5
"	HH	4.2	72.8	77.0

TABLE 9C

APPARENT MINERAL NITROGEN ACCUMULATION DUE TO DRIED BLOOD AND HOOF AND HORN

Soil	Treatment	3 weeks incubation NH_4-N	NO_3-N	min-N	6 weeks incubation NH_4-N	NO_3-N	min-N
G1	DB	8.3	2.3	10.6	0.3	28.8	29.1
"	HH	4.2	- 2.3	1.9	- 1.4	23.9	22.5
B1	DB	16.7	-15.0	1.7	1.0	4.9	5.9
"	HH	17.2	-14.3	2.9	- 1.5	22.8	21.3
R1	DB	45.6	-14.1	31.5	19.3	25.6	44.9
"	HH	45.0	-15.2	29.8	19.0	21.6	40.6

		12 weeks incubation		
G1	DB	0.3	43.9	44.2
"	HH	- 1.7	49.6	47.9
B1	DB	0.4	49.4	49.8
"	HH	- 1.6	50.0	48.4
R1	DB	18.2	39.2	57.4
"	HH	14.6	30.3	44.9

TABLE 9D

CARBON DIOXIDE RELEASE (Weeks)

(Results are in ppm on dry soil basis)

Soil	Treatment	0-3	3-6	0-6	6-12	0-12
G1	C	1380	600	1980	885	2865
"	DB	2040	645	2685	950	3635
"	HH	1920	745	2665	1020	3685
B1	C	1110	465	1575	875	2450
"	DB	1790	915	2705	1590	4295
"	HH	2040	700	2740	980	3720
R1	C	900	410	1310	840	2150
"	DB	1455	420	1875	730	2605
"	HH	1285	555	1840	895	2735

L.S.D ($P < 0.05$) CO_2 150

TABLE 9E

APPARENT RELEASE OF CARBONDIOXIDE FROM DB AND HH

Soil	Treatment	0-3	3-6	0-6	6-12	0-12
G1	DB	660	45	705	65	770
"	HH	540	145	685	135	820
B1	DB	680	450	1130	715	1845
"	HH	930	235	1165	105	1270
R1	DB	555	10	565	- 50	515
"	HH	385	145	530	55	585

in nitrate. In both the treated R1 soils mineralized N accumulated mainly as nitrate. After 12 weeks ammonium levels in all soils were similar to those after 6 weeks, but nitrate levels were higher after 12 weeks, particularly where DB and HH were added.

The apparent mineral N accumulation due to DB after 3 weeks decreased in the order R1, G1, B1. In the B1 and R1 soils nitrate decreased with both treatments, whilst ammonium decreased in the order G1, B1, R1. There was little change in nitrate in the G1 soil. After 6 weeks there was positive nitrate accumulation in all soils with both treatments, although the value was rather low with DB in the B1 soil. By 12 weeks of incubation the apparent mineralization of N from both DB and HH was of the same order. However, whereas in G1 and B1 mineralized N accumulated entirely as nitrate, in R1 about one-third of mineralized N accumulated as ammonium.

Carbon dioxide release

The apparent CO_2 release from DB during 0-3 weeks was similar with the three soils. However, with HH the apparent CO_2 release decreased in the order B1, G1, R1. During 0-6 weeks apparent CO_2 release from DB and HH was considerably higher from B1 than from G1 and R1 soils. The considerable increase from the B1 soil was accounted for by the high CO_2 release during the 3-6 week period. A considerable amount of CO_2 was released from DB in the B1 soil during 6-12 weeks. However, in the B1 soil with HH and the G1 and R1 soils with both treatments the apparent release of CO_2 during 6-12 weeks was relatively low compared with the earlier incubation periods.

During incubation the pH of the control G1 soil tended to increase, that of the R1 soil tended to decrease, whilst that of the B1 soil was little affected. However, after each incubation period the

DB and HH treatments of each soil did not differ by more than 0.2 units compared with the respective controls.

DISCUSSION

The lower accumulation of nitrate by 3 weeks in B1 and R1 soils treated with DB and HH compared with the control suggests that both added materials inhibited nitrification in these two soils during this period. By 6 weeks nitrate accumulated to about the same extent with both treatments in all three soils except with DB in the B1 soil. This suggests that some material(s) toxic to nitrification was formed by the 3-6 week period with DB in the B1 soil. However, by 12 weeks the toxic effect had disappeared and nitrate accumulation from DB was similar to that from HH.

The apparent mineralization of nitrogen from DB and HH was higher with R1 than with G1 and B1 soils to 3 weeks and was accounted for entirely as ammonium. This is presumably due to the lower pH of the R1 compared with the G1 and B1 soils. However during 3-6 weeks with R1 with both treatments mineralized N accumulated to about the same extent as ammonium and nitrate, whilst by 12 weeks nitrate accounted for about twice as much of the mineralized N as did ammonium. This suggests the possibility that heterotrophic nitrification in R1 increased with incubation time, although autotrophic nitrification was probably also operative. It was previously shown that addition of ammonium sulphate to the R1 soil inhibited nitrification in the early incubation stage, but by the end of incubation the inhibitory effect had largely disappeared.

The apparent carbon dioxide release from DB and HH is a measure of the rate of decomposition of these materials. There was a trend for both the added materials to decompose more rapidly in B1 than in

G1 and R1 in the early incubation stages, and the differences increased with incubation time. By 12 weeks the decomposition of DB was in the ratio 3.6, 1.5 and 1.0 for B1, G1 and R1 respectively. For HH the ratio were 2.2, 1.4 and 1.0 respectively. The main difference by 12 weeks was the lower decomposition of HH than of DB in the B1 soil.

In the G1 and R1 soils with DB all or most (86-100%) of the apparent decomposition of DB, as measured by carbon dioxide release, occurred during the first 3 weeks. In contrast to this only 37% of the DB in the B1 soil decomposed during the first 3 weeks. 73% of the HH in the B1 soil decomposed during the first 3 weeks, whilst HH in the G1 and R1 soils showed 66% decomposition during this period. The very small or nil decomposition of DB in the G1 and R1 soils during 6-12 weeks suggests that toxic products which accumulate early in incubation may have inhibited decomposition later in incubation. In B1, on the other hand, the high carbon dioxide release during 6-12 weeks suggests that no toxic products were produced. This indicates that the activity of the heterotrophic microorganisms decomposing the organic materials was higher in B1 than in the other two soils. Initially and after all stages of incubation mineral N was not limiting the activity of the heterotrophs decomposing carbonaceous materials in any soil with any treatment. The negative value (-50 ppm) for apparent decomposition of DB in the R1 soil during 6-12 weeks was less than the lowest significant difference (LSD) value (140 ppm) for carbon dioxide, and hence was not significant.

SUMMARY OF CHAPTER 6

Mineral N changes and carbon dioxide release during incubation over 12 weeks of G1, B1 and R1 soils treated with 100 ppm N as dried blood (DB) and hoof and horn (HH) were studied. The apparent mineral N accumulation due to DB and HH was higher in R1 than in G1 and B1 after 3 weeks. By 12 weeks of incubation, however, the amounts of N mineralized from DB and HH were of the same order. By 3 weeks in the R1 soil with DB and HH much more ammonium accumulated than in the other two soils with either treatment, and there was no apparent accumulation of nitrate from DB or HH in any of the soils. By 12 weeks apparent ammonium accumulation occurred only in the R1 soil with DB and HH. Apparent nitrate accumulation to 12 weeks was greater in G1 and B1 than in R1 with both treatments.

The apparent decomposition of DB and HH, as measured by carbon dioxide release, showed that both the added materials tended to decompose more rapidly in the early incubation stages in B1 than in G1 and R1, and the differences increased with incubation time. DB was decomposed to a greater extent than was HH in the B1 soil by 12 weeks. Decomposition of DB and HH in G1 and R1 by 12 weeks was much less than in B1. Decomposition of both added materials in G1 and R1 occurred mainly during the first 3 weeks. In the B1 soil with DB decomposition occurred uniformly over the whole incubation period, whilst with HH most of the decomposition occurred during the first 3 weeks.

CHAPTER 7

EFFECTS OF VARYING LEVELS OF SODIUM AS CHLORIDE AND SULPHATE ON MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1, B1 AND R1 SOILS TREATED WITH AMMONIUM SULPHATE (100 ppm N).

Experiment 9 G1 soil

Experiment 10 B1 soil

Experiment 11 R1 soil

CHAPTER 7

Experiment 9

G1 soil

Effects of varying levels of sodium as chloride and sulphate on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of G1 soil treated with ammonium sulphate (100 ppm) N.

METHODS

A bulk quantity of G1 soil was mixed with finely ground $(NH_4)_2SO_4$ to supply 100 ppm added N on the dry soil basis. Suitable quantities of soil were mixed with finely ground NaCl to supply 0.1, 0.25, 0.5 and 1.0% on the dry soil basis. Further quantities of soil were mixed with Na_2SO_4 to supply the same levels of sodium as in the chloride series. These soils, as well as a control soil containing only added $(NH_4)_2SO_4$, were set up for incubation at 30° and 50% saturation. Analyses were made initially and after 3 and 6 weeks of incubation and carbon dioxide release was also determined. The conductivity of 10g of each treatment shaken with 10 ml of water was determined after 6 weeks.

RESULTS

Results for mineral N levels and accumulation, carbon dioxide release and conductivity are shown in Table 10. Accumulation values are also shown in Fig. 6 and carbon dioxide release in Fig. 9.

Addition of 0.1% NaCl had negligible effects on nitrate and mineral N accumulation by 3 and 6 weeks compared with the control. Further increasing levels of NaCl caused decreasing nitrate accumulation until with 1.0% NaCl accumulation was virtually stopped. Mineral N accumulation declined similarly but was stopped by 0.5 and 1.0% NaCl.

TABLE 10

Chap. 7 Expt. 9

EFFECTS OF DIFFERENT LEVELS OF SODIUM AS CHLORIDE AND SULPHATE ON MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1 SOIL TREATED WITH AMMONIUM SULPHATE (100 ppm N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

NH_4-N	NO_3-N	min-N	pH
41.8	11.2	53.0	7.4

	L E V E L S				ACCUMULATION		
	After 3 weeks incubation						
% NaCl	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	0.7	78.8	79.5	7.6	-41.1	67.6	26.5
0.1	0.9	77.6	78.5	7.6	-40.9	66.4	25.5
0.25	1.9	61.2	63.1	7.6	-39.9	50.1	10.2
0.5	13.5	23.2	36.7	7.6	-28.3	12.0	-16.3
1.0	22.0	13.9	35.9	7.6	-19.8	2.7	-17.1
% Na_2SO_4 (Na equivalent to NaCl levels)[x]							
0.1	0.9	80.1	81.0	7.6	-40.9	68.9	28.0
0.25	0.8	77.6	78.4	7.5	-41.0	66.4	25.4
0.5	1.0	72.6	73.6	7.6	-40.8	61.4	20.6
1.0	1.3	37.7	39.0	7.6	-40.5	26.5	-14.0
% NaCl	After 6 weeks incubation						
0	1.0	88.3	89.3	7.7	-40.8	77.1	36.3
0.1	1.0	86.0	87.0	7.7	-40.8	75.2	34.4
0.25	1.6	69.6	71.2	7.6	-40.2	58.4	18.2
0.5	6.3	42.4	48.7	7.7	-35.5	31.2	- 4.3
1.0	21.0	17.6	38.6	7.7	-20.8	6.4	-14.4
% Na_2SO_4 (Na equivalent to NaCl levels)							
0.1	0.6	89.6	90.2	7.7	-41.2	78.4	37.2
0.25	0.5	89.2	89.7	7.7	-41.3	78.0	36.7
0.5	0.6	86.8	87.4	7.7	-41.2	75.6	34.4
1.0	0.6	78.7	79.3	7.7	-41.2	67.5	26.3

L.S.D ($P < 0.05$) NH_4-N 2.0, NO_3-N 3.2 and min-N 3.3

x NaCl added at levels indicated whilst Na_2SO_4 added to supply the same levels of Na as in the NaCl treatment.

TABLE 10 (continued)

CARBON DIOXIDE RELEASE (Weeks)

(Results are given in ppm on dry soil basis)

% NaCl	0-3	3-6	0-6
0	1605	635	2240
0.1	1550	650	2200
0.25	1485	830	2315
0.5	1285	825	2110
1.0	1140	870	2010
% Na_2SO_4 (Na equivalent to NaCl level)			
0.1	1565	810	2375
0.25	1510	740	2250
0.5	1710	650	2360
1.0	1705	835	2540

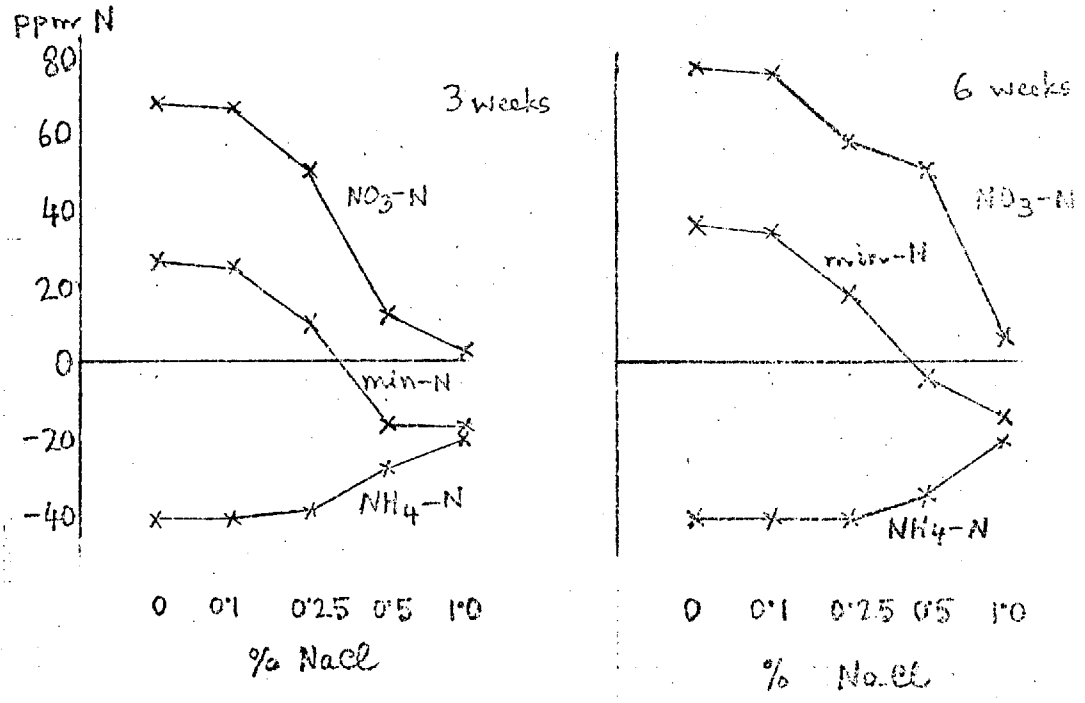
L.S.D ($P < 0.05$) 164

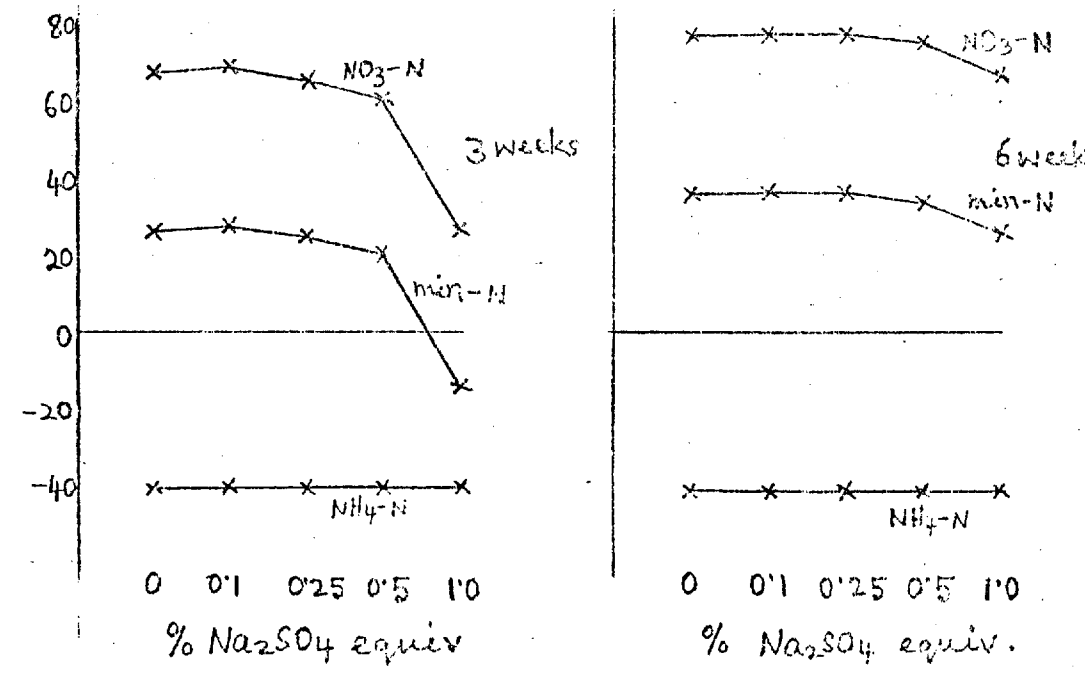
CONDUCTIVITY (after 6 weeks) OF 10 g SOIL SHAKEN WITH 10 ml OF WATER

% NaCl	µmhos per cm^3
0	1100
0.1	1950
0.25	3100
0.5	4900
1.0	8500
% Na_2SO_4	
0.1	1800
0.25	2700
0.5	4000
1.0	6000

CHAPTER 7 Experiment 9 G1 soil Fig.6

Effects of different levels of sodium as chloride and sulphate on mineral N changes during incubation to 6 weeks of G1 soil treated with 100 ppm N as ammonium sulphate.





There was a trend for nitrate accumulation to be higher by 6 than by 3 weeks, particularly with 0.5% NaCl.

With increasing levels of Na as sulphate up to 0.5% there were small decreases in nitrate and mineral N accumulation by 3 and 6 weeks. With 1% of the sulphate there were sharp decreases in the accumulation of both nitrate and mineral N by 3 weeks, but lesser decreases by 6 weeks. At this highest level of the sulphate form there were considerable increases in nitrate and mineral N during the 3-6 week period.

Carbon dioxide release over 0-3 weeks decreased moderately with increasing NaCl level, but with increasing Na_2SO_4 there were negligible changes in carbon dioxide release. By 6 weeks carbon dioxide release continued to show a slight decline with increasing NaCl, but only with 0.5 and 1.0%. By 6 weeks with Na_2SO_4 slight increases occurred with 0.1, 0.5 and 1.0% levels.

Conductivity values of the soil-water suspension with increasing levels of each form of sodium added increased to a greater extent with NaCl than with Na_2SO_4.

CHAPTER 7

Experiment 10

B1 soil

Effects of varying levels of sodium as chloride and sulphate on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of B1 soil treated with ammonium sulphate (100 ppm N).

METHODS

As in Experiment 9, except that B1 soil was used.

RESULTS

Table 11 shows results for mineral N levels and accumulation, carbon dioxide release and conductivity. Accumulation values are also shown in Fig. 7 and carbon dioxide release in Fig. 9.

By 3 weeks of incubation nitrate accumulation decreased with increasing levels of NaCl and was stopped by the 1.0% level. There was a similar trend to 6 weeks except that there was some further nitrate accumulation during 3-6 weeks with 0.1 and 0.5% and, particularly, with 0.25% NaCl. Mineral N accumulation decreased with increasing levels of NaCl and was stopped by 0.25% NaCl by 3 weeks and by 0.5% NaCl by 6 weeks. During 3-6 weeks there was some further accumulation of mineral N with 0.1 and 0.25% NaCl.

Nitrate accumulation decreased with increasing levels of Na_2SO_4 by 3 and 6 weeks, but the decrease was less than with the equivalent levels of NaCl. Nitrate accumulation by 6 weeks was slightly higher than by 3 weeks with 0.1, 0.25 and 0.5% Na_2SO_4. Mineral N accumulation also decreased with increasing levels of Na_2SO_4 and was stopped by 0.5% by 3 weeks and by 1.0% by 6 weeks.

Carbon dioxide release by 3 weeks decreased with increasing NaCl

TABLE 11

Chap.7 Expt. 10

EFFECTS OF DIFFERENT LEVELS OF SODIUM AS CHLORIDE AND SULPHATE ON MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF B1 SOIL TREATED WITH AMMONIUM SULPHATE (100 ppm N)

NITROGEN CHANGES
(Results are given in ppm on dry soil basis)

Initial values

NH_4-N	NO_3-N	min-N	pH
50.9	7.9	58.8	7.0

	L E V E L S				ACCUMULATION		
	After 3 weeks incubation						
% NaCl	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	0.8	74.5	75.3	6.5	-50.1	66.6	16.5
0.1	1.7	64.4	66.1	6.4	-49.2	56.5	7.3
0.25	3.4	37.8	41.2	6.4	-47.5	29.9	-17.6
0.5	15.7	20.4	36.1	6.4	-35.2	12.5	-22.7
1.0	23.5	10.7	34.2	6.5	-27.4	2.8	-24.6
% Na_2SO_4 (Na equivalent to NaCl levels)							
0.1	1.4	65.0	66.4	6.4	-49.5	57.1	7.6
0.25	1.7	62.1	63.8	6.4	-49.2	54.2	5.0
0.5	2.8	52.1	54.9	6.4	-48.1	44.2	-3.9
1.0	17.9	23.5	41.4	6.4	-33.0	15.6	-17.4
% NaCl	After 6 weeks incubation						
0	0.8	79.1	79.9	6.3	-50.1	71.2	21.1
0.1	0.8	72.5	73.3	6.3	-50.1	64.6	14.5
0.25	0.6	62.1	62.7	6.3	-50.3	54.2	3.9
0.5	13.4	25.8	39.2	6.4	-37.5	17.9	-19.6
1.0	20.3	6.6	26.9	6.4	-30.6	-1.3	-31.9
% Na_2SO_4 (Na equivalent to NaCl levels)							
0.1	0.6	74.4	75.0	6.4	-50.3	66.5	16.2
0.25	1.0	70.4	71.4	6.3	-49.9	62.5	12.6
0.5	1.8	63.2	65.0	6.4	-49.1	55.3	6.2
1.0	17.1	26.0	43.1	6.5	-33.8	18.1	-15.7

L.S.D ($P < 0.05$) NH_4-N 2.0, NO_3-N 3.3, min-N 3.4

TABLE 11 (continued)

CARBON DIOXIDE RELEASE (Weeks)

% NaCl	0-3	3-6	0-6
0	1205	600	1805
0.1	890	450	1340
0.25	770	790	1560
0.5	965	700	1665
1.0	995	660	1650
% Na_2SO_4			
0.1	1085	820	1905
0.25	1080	585	1665
0.5	1090	465	1555
1.0	970	515	1485

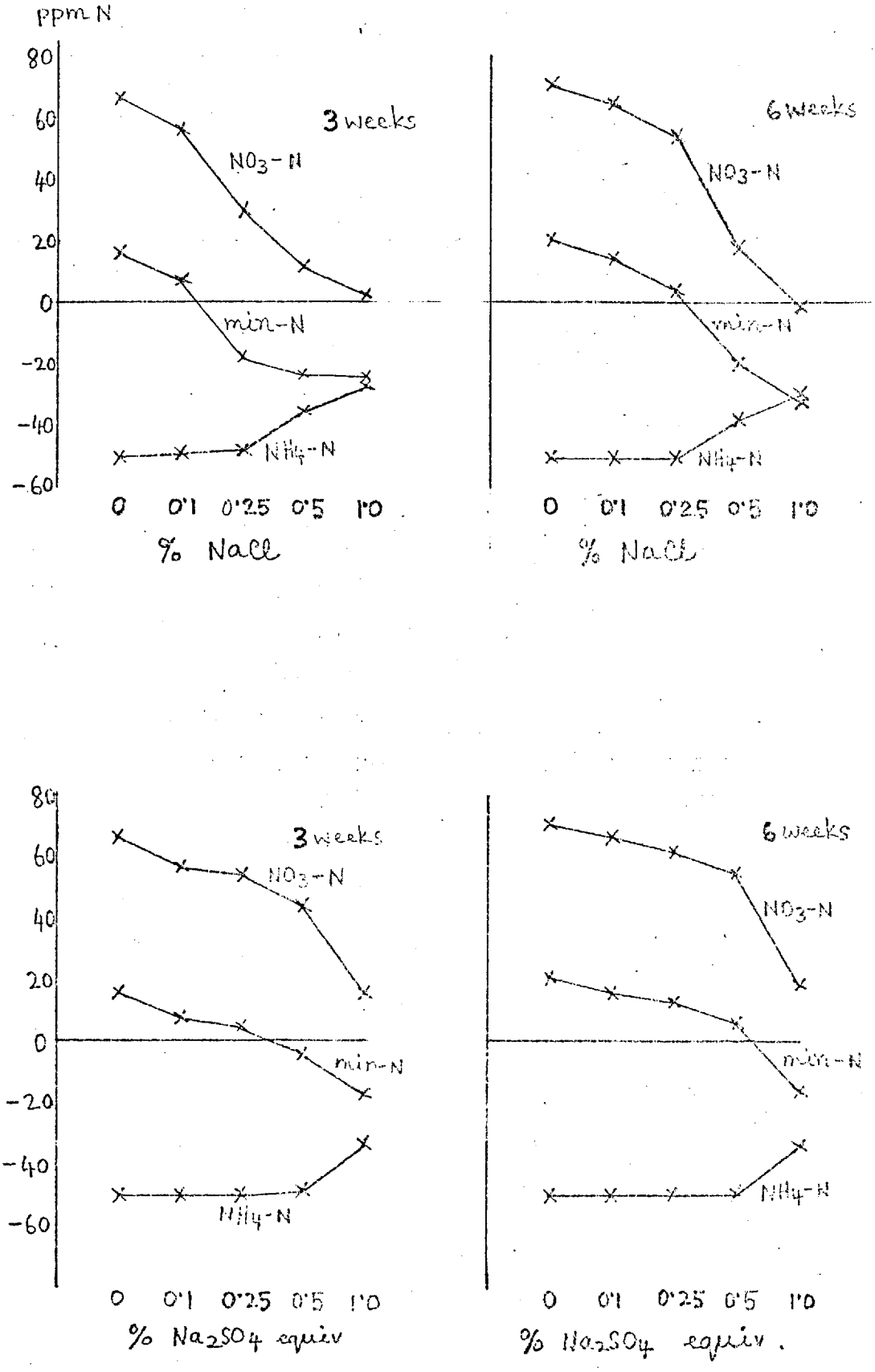
L.S.D ($P < 0.05$) 183

CONDUCTIVITY (after 6 weeks) OF 10g OF SOIL SHAKEN WITH 10 ml OF WATER

% NaCl	μmhos per cm^3
0	680
0.1	1450
0.25	2700
0.5	4400
1.0	7600
% Na_2SO_4	
0.1	1250
0.25	1900
0.5	3500
1.0	5000

CHAPTER 7 Experiment 10 B1 soil Fig.7

Effects of different levels of sodium as chloride and sulphate on mineral N changes during incubation to 6 weeks of B1 soil treated with 100 ppm N as ammonium sulphate.



levels up to 0.25%, whilst there were only small decreases with 0.5 and 1.0% NaCl. By 6 weeks carbon dioxide release was decreased to the greatest extent by 0.1% NaCl, but only to a moderate extent by higher levels. By 3 weeks carbon dioxide release decreased to about the same extent with all Na_2SO_4 levels. By 6 weeks it increased slightly with 0.1% Na_2SO_4, but decreased slightly with further increasing levels.

Conductivity values with increasing levels of each form of sodium salt added increased to a greater extent with NaCl than with Na_2SO_4.

CHAPTER 7

Experiment 11

R1 soil

Effects of varying levels of sodium as chloride and sulphate on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of R1 soil treated with ammonium sulphate (100 ppm N).

METHODS

As in Experiment 9, except that R1 soil was used.

RESULTS

Table 12 shows results for mineral N levels and accumulation, carbon dioxide release and conductivity. Accumulation values are also shown in Fig. 8 and carbon dioxide release in Fig. 9.

By 3 weeks of incubation all levels of NaCl stopped nitrate accumulation, whilst mineral N accumulation was hardly affected by any level of NaCl. Ammonium accumulation, on the other hand, was increased by 0.1% NaCl, but was little affected further by the higher NaCl levels. During 3-6 weeks there was moderate nitrate accumulation in the control soil and a little accumulation with 0.1% NaCl, but no further accumulation with the higher levels. By 6 weeks mineral N accumulation with all treatments was very similar to that after 3 weeks. Ammonium accumulation was increased considerably by 0.1% NaCl and only slightly more by the higher NaCl levels.

By 3 weeks nitrate accumulation was decreased by 0.1% Na_2SO_4, but was stopped by the higher levels. Mineral N accumulation by 3 weeks was increased by 0.25 and 0.5% Na_2SO_4 and decreased slightly by 0.1 and 1.0%. Ammonium accumulation increased somewhat with 0.1% Na_2SO_4 and further with 0.25 and 0.5%, but decreased somewhat with 1.0%. During 3-6 weeks nitrate accumulation increased to the same extent in

TABLE 12

Chap. 7 Expt. 11

EFFECTS OF DIFFERENT LEVELS OF SODIUM AS CHLORIDE AND SULPHATE ON MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF R1 SOIL TREATED WITH AMMONIUM SULPHATE (100 ppm N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

NH_4-N	NO_3-N	min-N	pH
101.4	4.0	105.4	4.9

	L E V E L S				ACCUMULATION		
	After 3 weeks incubation						
% NaCl	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
0	94.8	32.6	127.4	4.8	- 6.6	28.6	22.0
0.1	116.5	5.3	121.8	4.9	15.1	1.3	16.4
0.25	120.4	4.6	125.0	4.8	19.0	0.6	19.6
0.5	119.9	4.4	124.3	4.8	18.5	0.4	18.9
1.0	122.5	2.9	125.4	4.7	21.1	-1.1	20.0
% Na_2SO_4 (Na equivalent to NaCl levels)							
0.1	105.0	18.8	123.8	4.9	3.6	14.8	18.4
0.25	124.6	4.2	128.8	5.0	23.2	0.2	23.4
0.5	127.4	3.2	130.6	5.1	26.0	-0.8	25.2
1.0	114.8	3.2	118.0	5.1	13.4	-0.8	12.6
	After 6 weeks of incubation						
% NaCl							
0	70.0	61.6	131.6	4.4	-31.4	57.6	26.2
0.1	115.7	13.2	128.9	4.8	14.3	9.2	23.5
0.25	126.3	3.4	129.7	4.8	24.9	-0.6	24.3
0.5	127.7	3.4	131.1	4.8	26.3	-0.6	25.7
1.0	126.6	2.3	128.9	4.8	25.2	-1.7	23.5
% Na_2SO_4 (Na equivalent to NaCl levels)							
0.1	81.2	47.1	128.3	4.7	-20.2	43.1	22.9
0.25	107.0	24.1	131.1	4.8	5.6	20.1	25.7
0.5	125.5	6.7	132.2	5.1	24.1	2.7	26.8
1.0	137.2	2.8	140.0	5.1	36.8	-1.2	35.6

L.S.D ($P < 0.05$) NH_4-N 3.0, NO_3-N 2.1 and min-N 3.3

TABLE 12 (continued)

CARBON DIOXIDE RELEASE (Weeks)

(Results are given in ppm on dry soil basis)

% NaCl	0-3	3-6	0-6
0	1020	690	1710
0.1	795	450	1245
0.25	730	490	1220
0.5	860	580	1440
1.0	800	420	1220
% Na_2SO_4			
0.1	1035	545	1580
0.25	900	555	1455
0.5	825	490	1315
1.0	1140	800	1940

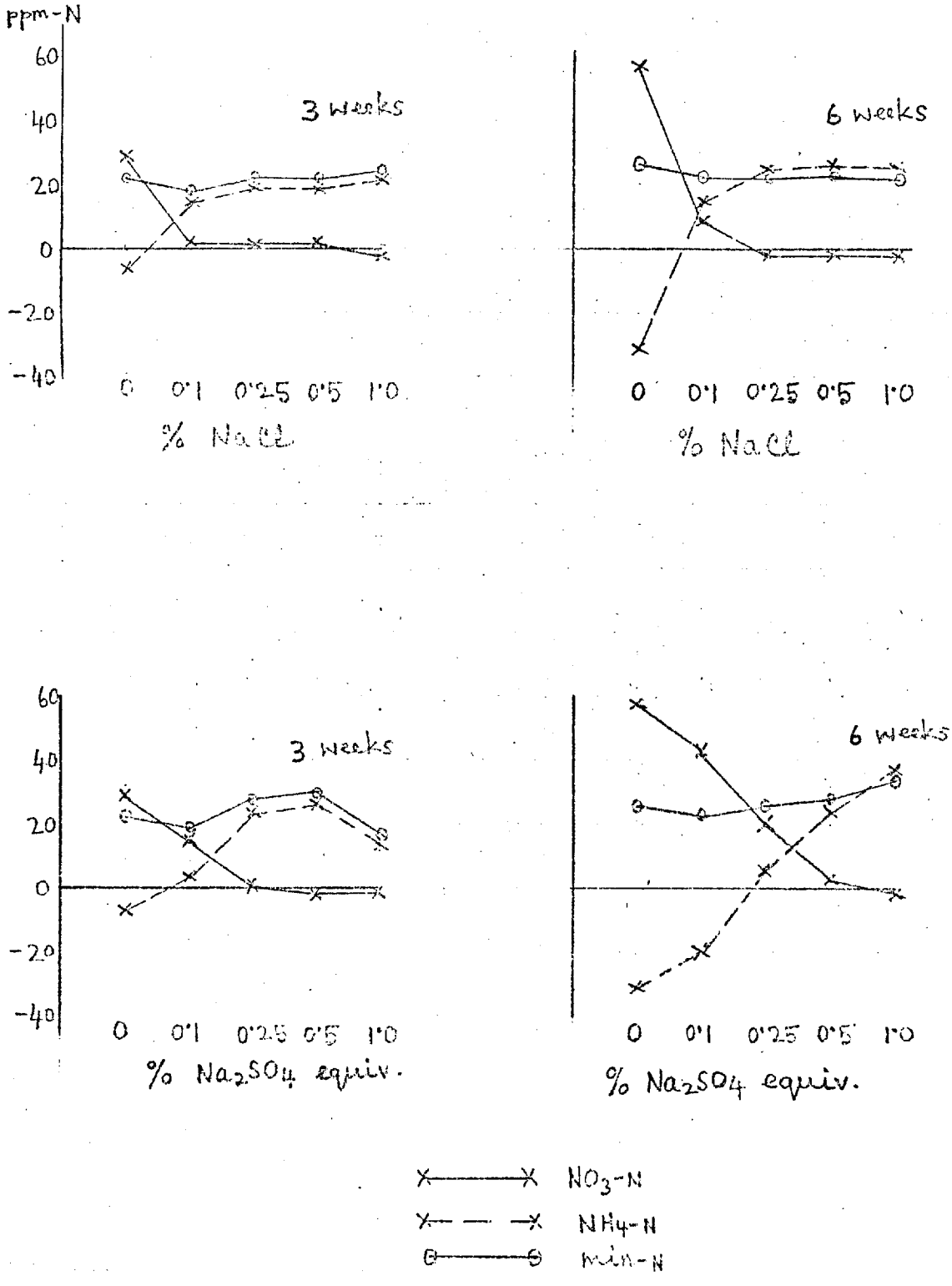
L.S.D ($P < 0.05$) 146

CONDUCTIVITY (after 6 weeks) OF 10g OF SOIL SHAKEN WITH 10 ml OF WATER

% NaCl	µmhos per cm^3
0	500
0.1	1350
0.25	2700
0.5	5000
1.0	9500
% Na_2SO_4	
0.1	1150
0.25	2400
0.5	4100
1.0	7500

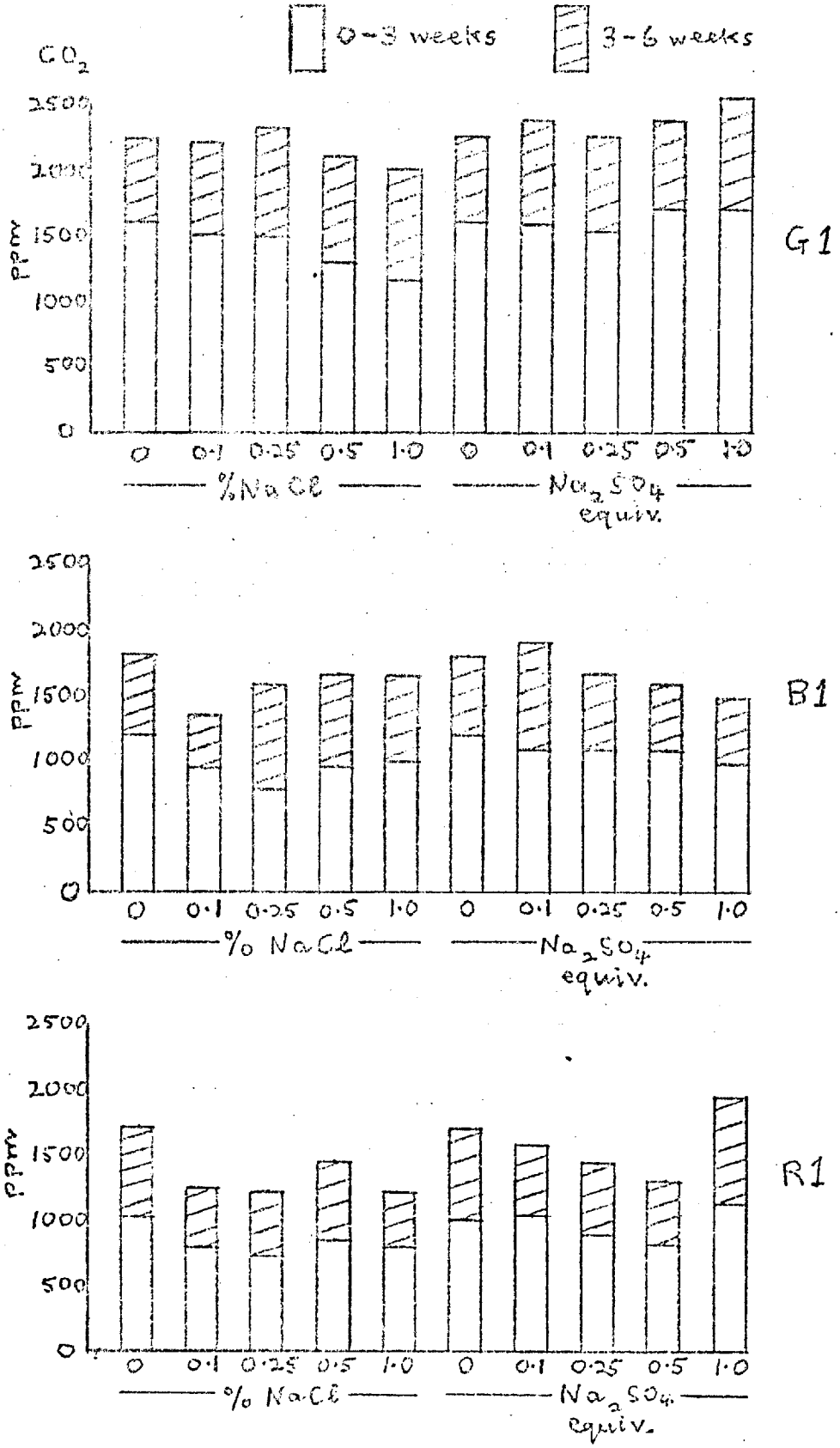
CHAPTER 7 Experiment 11 R1 soil Fig.8

Effects of different levels of sodium as chloride and sulphate on mineral N changes during incubation to 6 weeks of R1 soil treated with 100 ppm N as ammonium sulphate.



CHAPTER 7 Fig.9 Expts.9, 10 and 11
G1, B1 and R1 soils

Effects of different levels of sodium as chloride and sulphate on carbon dioxide release during incubation over 6 weeks of G1, B1 and R1 soils treated with 100 ppm N as ammonium sulphate.



the control and with 0,1 and 0.25% Na_2SO_4, but was stopped by the two higher levels. By 6 weeks only the 1.0% Na_2SO_4 treatment increased mineral N accumulation compared with 3 weeks. By 6 weeks ammonium accumulation declined compared with 3 weeks in the control and with 0.1 and 0.25% Na_2SO_4, was not affected by 0.5% and was increased by 1.0%.

By 3 weeks carbon dioxide release was decreased to about the same extent by all levels of NaCl. By 6 weeks there was less decrease with 0.5% NaCl than with the other levels. By 3 weeks with Na_2SO_4 carbon dioxide release was decreased only by the 0.5% level. By 6 weeks carbon dioxide release declined with increasing level of Na_2SO_4 to 0.5%, but was increased by 1.0%.

Conductivity values with increasing level of each form of added sodium salt increased to a greater extent with NaCl than with Na_2SO_4.

DISCUSSION OF CHAPTER 7

Decreased N mineralization and nitrification in the G1 and B1 soils due to addition of NaCl and Na_2SO_4 is probably due to plasmolysis effects on some of the types of heterotrophs responsible for the conversion of organic nitrogenous compounds to ammonium. Autotrophic nitrifiers as well as heterotrophic nitrifiers (which may be present in the R1 soil) could be affected in the same way. In addition sodium, chloride and sulphate ions could have direct toxic effects on the microorganisms. The heterotrophs responsible for mineralization of N in soils are bacteria, fungi and actinomycetes. In acid soils (e.g. R1) it is generally accepted that fungi are more active than the other two groups (1), whereas in soils of higher pH (e.g. G1 and B1) bacteria are mainly operative.

The G1 and B1 soils, which have rather similar properties (with regard to texture and clay type, organic carbon and nitrogen contents and pH), behaved similarly in some respects with regard to the changes in mineral N forms brought about by addition of varying levels of NaCl and Na_2SO_4. However, there were some significant and important differences between the responses of these two soils. For example, addition of 0.1% NaCl had little effect on nitrification and N mineralization in the G1 soil, but decreased both processes in the B1 soil. With the two highest levels of NaCl, however, the toxic effects were similar in both soils, although during 3-6 weeks with 0.5% NaCl nitrification was greater in G1 than in B1. This suggests that part of the toxic effect was only temporary in G1 and during the latter 3-week period the microorganisms involved had adapted themselves to some extent so as to operate under the new conditions, and bring about further nitrification. With 0.25% NaCl there was evidence of this adaptation in both soils. With regard to N mineralization the

toxic effects of increasing levels of NaCl were greater in B1 than in G1. There was also some adaptation of the N mineralizing organisms in both soils at all NaCl levels except 1.0%.

With the Na_2SO_4 treatments the increasing toxicity due to increasing levels of this salt was greater in B1 than in G1 with respect to both N mineralization and nitrification. The other main difference between the two soils occurred with 1.0% Na_2SO_4 addition, where there were considerable increases in nitrification and N mineralization during 3-6 weeks, but only in the G1 soil. In general there was considerable adaptation of N mineralizing and nitrifying organisms to the initial toxic effects of both salts in G1 but much less adaptation in B1. This suggests differences in the nature of the microorganisms operative in these two soils.

In both G1 and B1 soils increasing levels of NaCl were more toxic to N mineralizing and nitrifying organisms than were increasing levels of Na_2SO_4. This indicates that chloride levels were more toxic than were equivalent levels of sulphate. The lower toxicity of sulphate compared with chloride is probably due to the fact that the former anion is metabolised within the cells of the N mineralizing and nitrifying organisms and thus were prevented from accumulating to toxic levels. On the other hand, since chloride is only slightly metabolized it rapidly accumulates to toxic levels within the cell.

The conductivity measurement of the soils showed that at each level of sodium conductivity was always greater where it was added as chloride than as sulphate and the differences increased with increasing levels of the added salts. This indicates higher osmotic pressure with the chloride than with the equivalent sulphate levels, which could in part account for the greater toxicity where sodium was added as chloride than as sulphate.

The decrease in mineral N to negative values with levels of NaCl of 0.5 and 1.0% in the G1 soil is probably due to immobilization of ammonium or nitrate. This immobilization is probably due to the death of some types of heterotrophs initially or early in incubation. Those heterotrophs which survived presumably attacked the dead organisms and immobilized some mineral N in the process. The B1 soil behaved similarly except that the immobilizing effect occurred with 0.25% as well as the higher levels of NaCl. In the G1 soil with the sulphate treatments immobilization occurred only with the 1.0% level and then only by 3 weeks. During 3-6 weeks residual organic nitrogenous materials mineralized, with mineralized N being accounted for entirely as nitrate. In the B1 soil with 1.0% Na_2SO_4 immobilization also occurred by 3 weeks, but persisted to 6 weeks. This indicates yet another difference in the microbiological properties between the two soils.

The main difference between the R1 soil on the one hand and B1 and G1 soils on the other hand was the fact that even 0.1% NaCl stopped nitrification in R1, whilst in the two other soils this level of NaCl had little effect on nitrification. This suggests a difference in the types of nitrifying organisms in R1 compared with the other two soils. It is possible that a heterotrophic process is responsible for nitrification in R1 and the organism(s) involved happen to be particularly susceptible to even 0.1% NaCl. Nitrification in R1 was also stopped by 0.25% Na_2SO_4, whilst even 1.0% of this salt did not stop nitrification in G1 and B1. Another difference between R1 and the other two soils was that mineralization of N (accumulation of mineral N) was not much affected in R1 by any level of either salt, whilst in G1 and B1 N mineralization was generally decreased to a fair extent with increasing levels of both salts. It is likely that

in the slightly alkaline G1 and B1 soils bacteria are mainly responsible for N mineralization, whereas in the acid R1 soil fungi are responsible. This suggests that bacteria are more susceptible to increasing salt levels than are fungi.

Changes in carbon dioxide release due to varying levels of either added salt were relatively small compared with changes in mineral N levels. The three soils behaved rather differently with respect to changes in carbon dioxide release due to added salts. In G1 only 0.5 and 1.0% NaCl decreased carbon dioxide release, whilst in B1 and R1 there were fair decreases even with 0.1% NaCl. With increasing Na_2SO_4 levels in G1 only the 1.0% level increased carbon dioxide release. In B1 0.1 and 0.25% Na_2SO_4 had no effect but there was a small decrease in carbon dioxide release with the two higher levels. In R1 carbon dioxide release decreased with increasing Na_2SO_4 up to 0.5%, whilst 1.0% increased carbon dioxide release. In some cases carbon dioxide release during the 3-6 week period was significantly greater in treated soils than in the control. This applied particularly with 1.0% Na_2SO_4 in G1 and R1 and with 0.25 to 1.0% NaCl in G1. On the other hand 1.0% NaCl in R1 caused decreased carbon dioxide release during the 3-6 week period, indicating that the toxic effect persisted throughout 6 weeks. Where carbon dioxide release increased during the second 3-week period this was probably due to the decomposition by those heterotrophs, which survived the initial effects of the salts, attacking the dead microbial tissue, left from early in incubation, during the second 3-week period to release further carbon dioxide.

SUMMARY OF CHAPTER 7

G1, B1 and R1 soils were mixed with ammonium sulphate to supply 100 ppm added N. Subsamples of this soil were mixed with 0.0, 0.25, 0.5 and 1.0% NaCl. Further subsamples were mixed with Na_2SO_4 to supply the same levels of sodium as in the chloride series. These soils and their controls (containing only added ammonium sulphate) were set up for incubation at 30° and 50% saturation. Analyses for mineral N were made initially and after 3 and 6 weeks of incubation, and carbon dioxide release was also determined.

In the G1 and B1 soils 0.1% NaCl had no effect on or decreased nitrification only slightly by 3 weeks of incubation. Nitrification decreased further with increasing NaCl levels and was stopped by 1.0% NaCl. During the 3-6 week incubation period nitrate accumulated to a moderate extent in G1 and B1 where 0.25 and 0.5% NaCl was added. In the R1 soil nitrification was stopped even by 0.1% NaCl as well as by the higher salt levels by 3 weeks, but by 6 weeks there was some nitrate accumulation, but only with 0.1% NaCl. Mineralization of N (ammonia plus nitrate accumulation) in G1 and B1 decreased with increasing NaCl and was stopped by 0.5 and 1.0% NaCl in G1 and by 0.25 to 1.0% NaCl levels in B1. In the R1 soil N mineralization was not affected by any level of NaCl.

Mineral N changes during incubation due to increasing levels of Na_2SO_4 were generally smaller than those due to increasing NaCl levels. In the G1 soil up to 0.5% Na_2SO_4 decreased nitrification and N mineralization only slightly, whilst 1.0% decreased nitrification considerably and stopped N mineralization. In B1 nitrification was decreased moderately by up to 0.5% Na_2SO_4, but to a greater extent by 1.0%. N mineralization decreased with increasing level of Na_2SO_4

and was stopped by 0.5 and 1.0% levels by 3 weeks, but only by the 1.0% level after 6 weeks. In the R1 soil nitrification was decreased by 0.25% Na_2SO_4 after 3 weeks and by 0.5 and 1.0% after 6 weeks. There was some accumulation of nitrate during 3-6 weeks with 0.1 and 0.25% Na_2SO_4. The R1 soil was the only one in which mineralized N accumulated as ammonium with the higher Na_2SO_4 and NaCl levels.

Carbon dioxide release from all soils was affected much less by increasing levels of both added salts than were mineral N levels. Average carbon dioxide release declined in the order G1, B1, R1. 0.1% NaCl had no effect on carbon dioxide release from G1 but decreased it from B1 and R1. With the higher NaCl levels carbon dioxide release was barely affected further in G1 and R1 but was increased in B1. With the Na_2SO_4 treatment only 1.0% increased carbon dioxide release from G1 and R1. In B1 only 0.5 and 1.0% whilst in R1 only 0.25 and 0.5% Na_2SO_4 decreased carbon dioxide release.

CHAPTER 8

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1, B1 AND R1 SOILS AT VARYING MOISTURE LEVELS WITHOUT AND WITH ADDITION OF AMMONIUM NITRATE (100 ppm N).

Experiment 12 G1 soil

Experiment 13 B1 soil

Experiment 14 R1 soil

CHAPTER 8

Experiment 12

G1 soil

Mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of G1 soil at varying moisture levels without and with addition of ammonium nitrate (100 ppm N).

METHODS

A bulk quantity of G1 soil was mixed with finely ground ammonium nitrate to supply 100 ppm added N. 10g portions of the treated soil as well as untreated soil (no N added) were set up in duplicate for incubation at 30^{o} and at moisture contents of 25, 50, 75, 100 and 133% saturation. The highest moisture content represented a waterlogged condition. Sufficient tubes of all treatments were set up for analysis for mineral N initially and after 3 and 6 weeks of incubation, and carbon dioxide release was also determined.

RESULTS

Table 13 shows results for levels and accumulation of mineral N, and carbon dioxide release. Fig. 10 shows mineral N accumulation values and Fig. 13 shows carbon dioxide release.

Where no N was added nitrate accumulation increased with moisture content up to 75% saturation and decreased with further increasing moisture. There was some nitrate accumulation at 100% saturation by 3 weeks, but this disappeared by 6 weeks. Where N was added maximum nitrate accumulation by 3 and 6 weeks occurred at 50% saturation. By 3 weeks there was some nitrate accumulation at 100% saturation, but considerable loss at 133% saturation. By 6 weeks there was loss of nitrate even at 100% saturation.

TABLE 13

Chap. 8 Expt. 12

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1 SOIL AT VARYING MOISTURE LEVELS WITHOUT AND WITH ADDITION OF 100 ppm N AS AMMONIUM NITRATE.

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

Levels	NH_4-N	NO_3-N	min-N	pH
0	6.0	12.0	18.0	7.5
N	33.5	60.4	93.9	7.4

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
% Sat.	N	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
25	0	0.6	26.7	27.3	7.9	- 5.4	14.7	9.3
"	N	5.1	77.3	82.4	7.8	-28.4	16.9	-11.5
50	0	0.5	36.6	37.1	8.0	- 5.5	24.6	19.1
"	N	1.3	99.6	100.9	7.6	-32.2	39.2	7.0
75	0	0.6	38.6	39.2	7.9	- 5.4	26.6	21.2
"	N	0.8	95.8	96.6	7.6	-32.7	35.4	2.7
100	0	0.6	28.1	28.7	7.9	- 5.4	16.1	10.7
"	N	1.4	81.5	82.9	7.6	-32.1	21.1	-11.0
133	0	7.0	2.8	9.8	7.4	1.0	- 9.2	- 8.2
"	N	10.7	1.1	11.8	7.2	-22.8	-59.3	-82.1
		After 6 weeks incubation						
25	0	0.5	37.8	38.3	7.9	- 5.5	25.8	20.3
"	N	2.0	94.4	96.4	7.8	-31.5	34.0	2.5
50	0	0.5	43.0	43.5	8.0	- 5.5	31.0	25.5
"	N	1.6	109.9	111.5	7.9	-31.9	49.5	17.6
75	0	0.7	45.7	46.4	8.0	- 5.3	33.7	28.4
"	N	0.9	106.3	107.2	7.9	-32.6	45.9	13.3
100	0	3.8	2.1	5.9	7.7	- 2.2	- 9.9	-12.1
"	N	8.4	49.0	57.4	7.7	-25.1	-11.4	-36.5
133	0	6.2	1.6	7.8	7.4	0.2	-10.4	-10.2
"	N	8.4	2.1	10.5	7.4	-25.1	-58.3	-83.4

L.S.D ($P < 0.05$) NH_4-N 1.1, NO_3-N 3.3 and min-N 3.7

TABLE 13 (continued)

CARBON DIOXIDE RELEASE (Weeks)

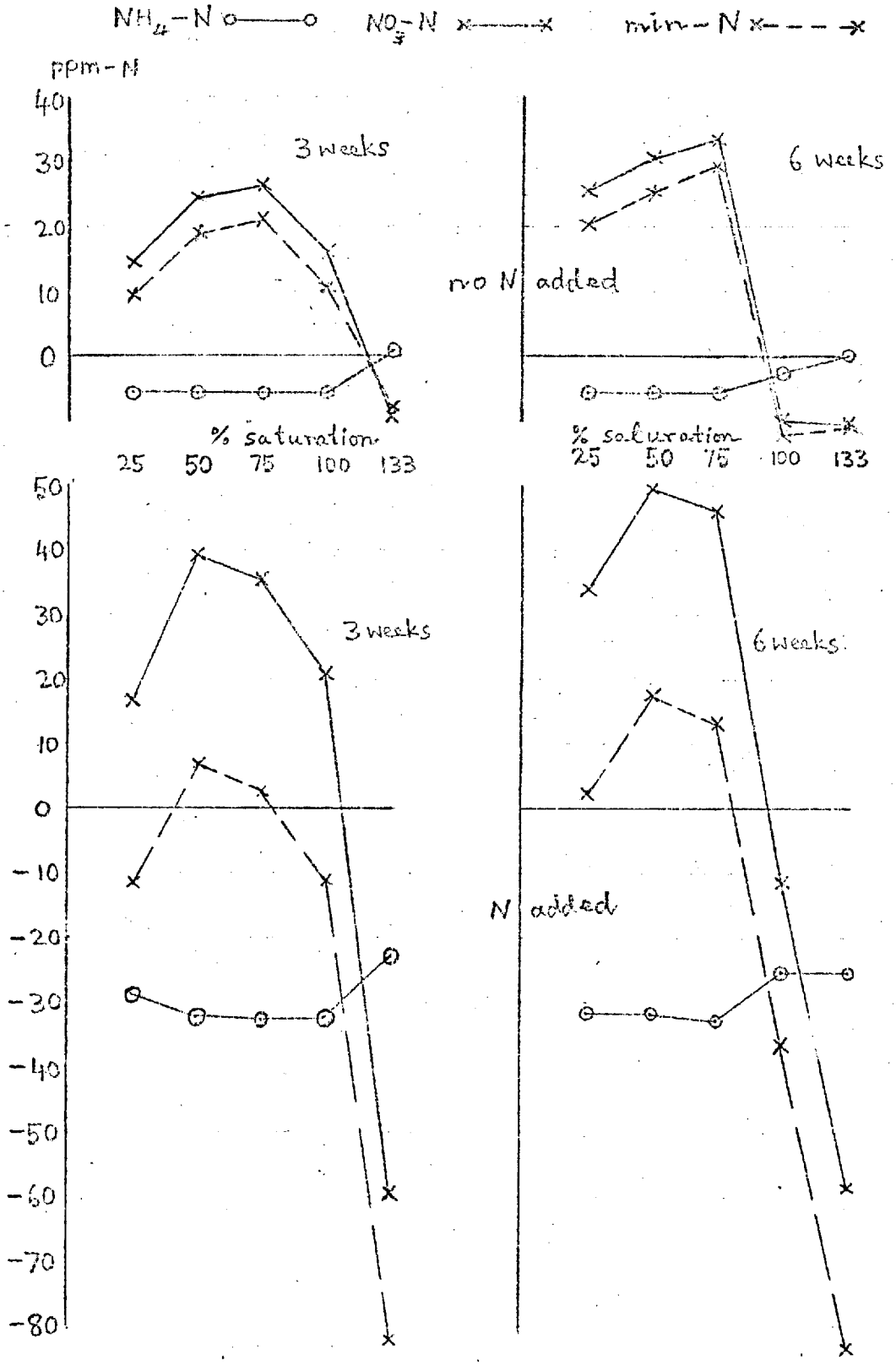
(Results are given in ppm on dry soil basis)

% Moisture Level	N-Level	0-3	3-6	0-6
25	0	890	585	1475
"	N	1495	850	2345
50	0	1115	820	1935
"	N	1735	1130	2865
75	0	1035	800	1835
"	N	1725	1245	2970
100	0	1340	650	1990
"	N	1485	1405	2890
133	0	925	610	1535
"	N	950	1085	2035

L.S.D ($P < 0.05$) 201

CHAPTER 8 Expt.12 G1 soil Fig.10

Mineral N accumulation during incubation to 6 weeks of G1 soil at varying moisture levels without and with addition of 100 ppm N as ammonium nitrate.



Accumulation values for mineral N roughly paralleled those for nitrate whether or not N was added, except that accumulation was much lower or there was more loss of mineral N where N was added.

Changes in ammonium levels with increasing soil moisture were similar after 3 and 6 weeks whether or not N was added. Loss of ammonium differed relatively slightly with increasing moisture from 25 to 100% saturation, but there was somewhat less loss at 133% saturation by 3 weeks and at 100 and 133% saturation by 6 weeks where N was added. Average loss of ammonium was greater where N was added.

Where no N was added carbon dioxide release by 3 weeks was greatest at 100% saturation, whilst by 6 weeks it was greatest at 50 to 100% saturation. Where N was added carbon dioxide release by 3 weeks was greatest at 50 and 75% saturation and least at 133% saturation. By 6 weeks carbon dioxide release was greatest at 50 to 100% saturation and least at 133%.

Whether or not N was added, pH by 3 and 6 weeks differed little with varying moisture levels of 25 to 100% saturation, but was decreased slightly at 133% saturation.

CHAPTER 8

Experiment 13

B1 soil

Mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of B1 soil at varying moisture levels without and with addition of ammonium nitrate (100 ppm N).

METHODS

As in Expt. 12, except that B1 soil was used.

RESULTS

Table 14 shows results for mineral N levels and accumulation, and carbon dioxide release. Fig. 11 shows mineral N accumulation and Fig. 13 shows carbon dioxide release.

Nitrate accumulation by 3 and 6 weeks where no N was added was slightly higher at 50 and 75% saturation than at 25%, but there was no nitrate accumulation at 100 and 133% saturation. Where N was added nitrate was moderately higher by 6 than by 3 weeks at 25% saturation. Maximum nitrate accumulation after both periods occurred at 50% saturation, but accumulation at 75% was not much less. There was considerable loss of nitrate by 3 and 6 weeks at 100 and 133% saturation where N was added.

Where no N was added accumulation values for mineral N differed little from those for nitrate after 3 and 6 weeks at each moisture content. Where N was added mineral N accumulation paralleled that of nitrate accumulation, but at each saturation level mineral N accumulation was lower or there was more loss of mineral N.

Where no N was added there was slight loss of ammonium to about the same extent at 25 to 75% saturation by 3 and 6 weeks, whilst at 100 and 133% saturation there was a slight gain in or no effect on

TABLE 14

Chap. 8 Expt. 13

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF B1 SOIL AT VARYING MOISTURE LEVELS WITHOUT (O) AND WITH ADDITION OF 100 ppm-N AS AMMONIUM NITRATE (N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

N added	NH_4-N	NO_3-N	min-N	pH
0	4.1	5.3	9.4	7.4
N	31.0	53.0	84.0	7.0

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
% Sat	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
25	0	0.7	29.4	30.1	6.9	- 3.4	24.1	20.7
"	N	1.4	83.3	84.7	6.5	-29.6	30.3	0.7
50	0	0.7	33.8	34.5	7.0	- 3.4	28.5	25.1
"	N	0.5	98.7	99.2	6.4	-30.5	45.7	15.2
75	0	0.8	34.5	35.3	7.1	- 3.3	29.2	25.9
"	N	0.6	94.4	95.0	6.4	-30.4	41.4	11.0
100	0	6.6	3.9	10.5	7.2	2.5	- 1.4	1.1
"	N	5.1	2.5	7.6	6.9	-25.9	-50.5	-76.4
133	0	7.7	2.6	10.3	7.2	3.6	- 2.7	0.9
"	N	9.0	2.5	11.5	7.3	-22.0	-50.5	-72.5
		After 6 weeks incubation						
25	0	1.0	37.0	38.0	6.9	- 3.1	31.7	28.6
"	N	0.5	96.2	96.7	6.4	-30.5	43.2	12.7
50	0	0.9	40.2	41.1	6.9	- 3.2	34.9	31.7
"	N	0	102.1	102.1	6.3	-31.0	49.1	18.1
75	0	1.1	41.7	42.8	7.1	- 3.0	36.4	33.4
"	N	0	98.0	98.0	6.4	-31.0	45.0	14.0
100	0	3.1	6.0	9.1	7.3	- 1.0	0.7	- 0.3
"	N	2.6	1.4	4.0	7.0	-28.4	-51.6	-80.0
133	0	5.5	4.3	9.8	7.1	1.4	- 1.0	0.4
"	N	7.7	2.2	9.9	7.0	-23.3	-50.8	-74.1

L.S.D ($P < 0.05$) NH_4-N 1.5, NO_3-N 3.0 and min-N 3.1

TABLE 14 (continued)

CARBON DIOXIDE RELEASE (Weeks)

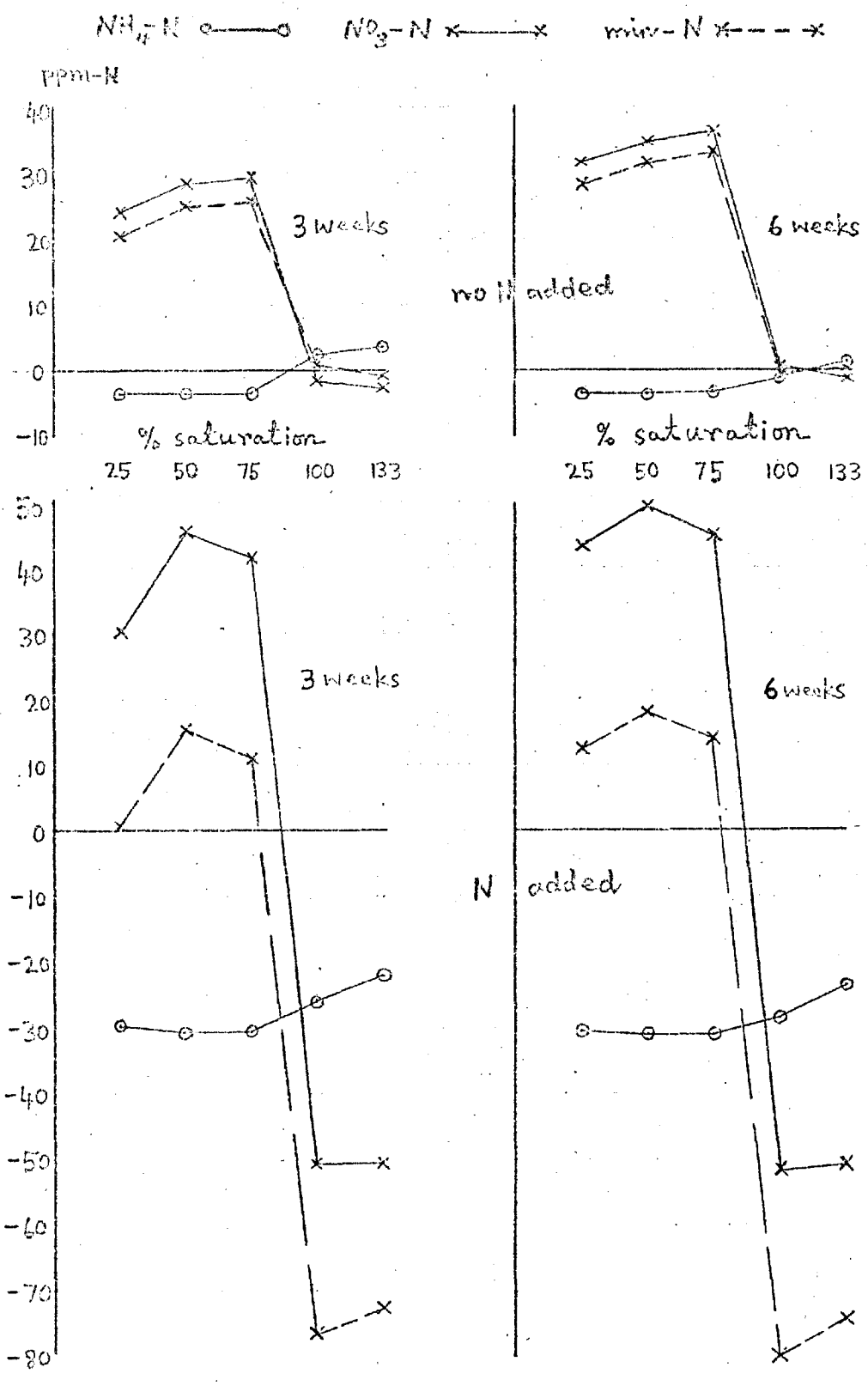
(Results are given in ppm on dry soil basis)

% sat.	N added	0-3	3-6	0-6
25	0	835	320	1155
"	N	885	410	1295
50	0	1155	555	1710
"	N	1020	610	1630
75	0	1090	595	1685
"	N	1090	560	1650
100	0	1180	555	1735
"	N	1160	635	1795
133	0	885	585	1470
"	N	990	605	1595

L.S.D ($P < 0.05$) 205

CHAPTER 8 Expt.13 B1 soil Fig.11

Mineral N accumulation during incubation to 6 weeks of B1 soil at varying moisture levels without and with addition of 100 ppm N as ammonium nitrate.



ammonium accumulation. Where N was added ammonium decreased to the same extent at 25 to 75% saturation, but decreased slightly less at 100 and 133% saturation.

Where no N was added carbon dioxide release by 3 and 6 weeks was somewhat higher at 50 to 100% saturation than at 25 and 133% saturation. Where N was added carbon dioxide release by 3 weeks was higher at 100% saturation than at the other moisture levels, among which there were no significant differences. By 6 weeks carbon dioxide release at 25% saturation was less than at all higher moisture levels, among which there were no significant differences.

By 3 and 6 weeks of incubation where no N was added pH increased slightly with moisture level. Where N was added pH after 3 and 6 weeks was slightly lower at 25 to 75% saturation but not at the two highest moisture levels when compared with the no added N treatments.

CHAPTER 8

Experiment 14

R1 soil

Mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of R1 soil at varying moisture levels without and with addition of ammonium nitrate (100 ppm N).

METHODS

As in Expt. 12, except that R1 soil was used.

RESULTS

Table 15 shows results for mineral N levels and accumulation and carbon dioxide release. Fig. 12 shows mineral N accumulation and Fig. 13 shows carbon dioxide release.

By 3 weeks nitrate accumulation occurred only at 25 and 50% saturation and there was no nitrate accumulation at 75% saturation. At 100 and 133% saturation there was some loss of nitrate. With incubation up to 6 weeks there were further increases in nitrate at all moisture levels up to 100% saturation, but particularly at 75 and 100%. However there was still a net loss in nitrate at 133% saturation. Where N was added there was small accumulation of nitrate by 3 weeks, but only at 50 and 75% saturation, but there was considerable loss of nitrate at 100 and 133% saturation. By 6 weeks nitrate increased considerably at 50 and 75% saturation, but there were no further changes at the other moisture levels.

Mineral N accumulation by 3 weeks where no N was added increased with moisture content, although the differences were small from 50 to 100% saturation. By 6 weeks mineral N accumulation was somewhat higher than by 3 weeks at each moisture level. Where N was added mineral N accumulation by 3 and 6 weeks was very similar at 25 to 75%

TABLE 15

Chap. 8 Expt. 14

MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF R1 SOIL AT VARYING MOISTURE LEVELS WITHOUT (O) AND WITH ADDITION OF 100 ppm-N AS AMMONIUM NITRATE (N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

N added	NH_4-N	NO_3-N	min-N	pH
0	10.6	4.4	15.0	5.0
N	57.4	52.7	110.1	4.8

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
% sat	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
25	0	11.2	14.0	25.2	5.1	0.6	9.6	10.2
"	N	69.3	52.8	122.1	4.8	11.9	0.1	12.0
50	0	14.6	18.5	33.1	4.9	4.0	14.1	18.1
"	N	72.8	54.6	127.4	4.7	15.4	1.9	17.3
75	0	26.6	6.4	33.0	5.9	16.0	2.0	18.0
"	N	69.4	58.3	127.7	4.7	12.0	5.6	17.6
100	0	33.6	1.4	35.0	6.5	23.0	- 3.0	20.0
"	N	88.5	1.1	89.6	6.4	31.1	-51.6	-20.5
133	0	42.0	1.2	43.2	6.7	31.4	- 3.2	28.2
"	N	82.4	1.1	83.5	6.5	25.0	-51.6	-26.6
		After 6 weeks incubation						
25	0	5.6	23.0	28.6	4.9	- 5.0	18.6	13.6
"	N	72.8	56.0	128.8	4.9	15.4	3.3	18.7
50	0	5.3	32.8	38.1	4.7	- 5.3	28.4	23.1
"	N	50.4	77.0	127.4	4.5	- 7.0	24.3	17.3
75	0	3.5	38.2	41.7	4.6	- 7.1	33.8	26.7
"	N	44.8	84.0	128.8	4.4	-12.6	31.3	18.7
100	0	2.0	37.0	39.0	4.6	- 8.6	32.6	24.0
"	N	49.0	19.0	68.0	6.4	- 8.4	-33.7	-42.1
133	0	46.1	1.5	47.6	6.7	35.5	- 2.9	32.6
"	N	64.0	0	64.0	6.6	6.6	-52.7	-46.1

L.S.D ($P < 0.05$) NH_4-N 2.2, NO_3-N 1.9 and min-N 3.1

TABLE 15 (continued)

CARBON DIOXIDE RELEASE (Weeks)

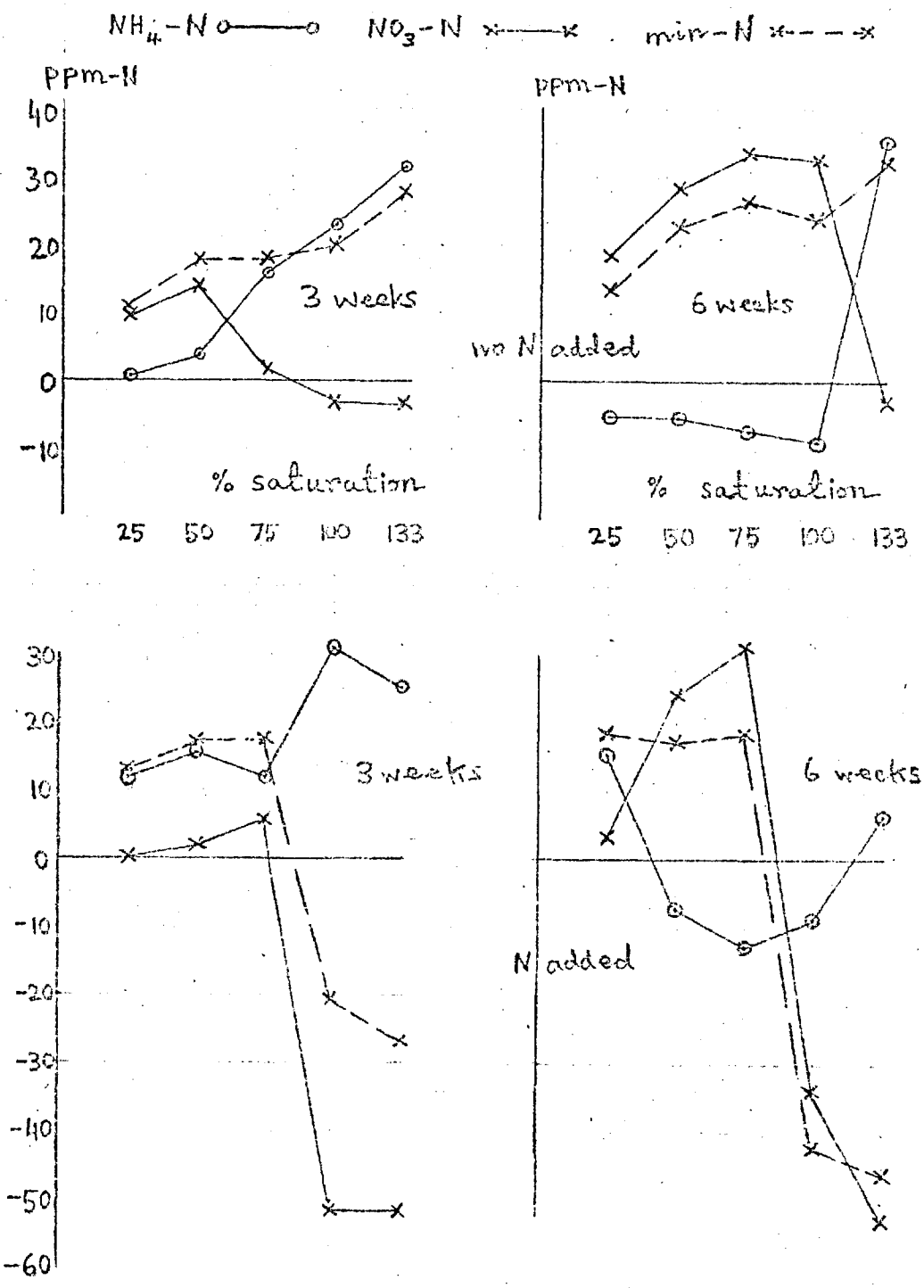
(Results are given in ppm on dry soil basis)

% saturation	N added	0-3	3-6	0-6
25	0	680	320	1000
"	N	885	365	1250
50	0	955	630	1585
"	N	1075	515	1590
75	0	1135	740	1875
"	N	1150	675	1825
100	0	965	560	1525
"	N	1175	1045	2220
133	0	955	600	1555
"	N	1150	965	2115

L.S.D ($P < 0.05$) 180

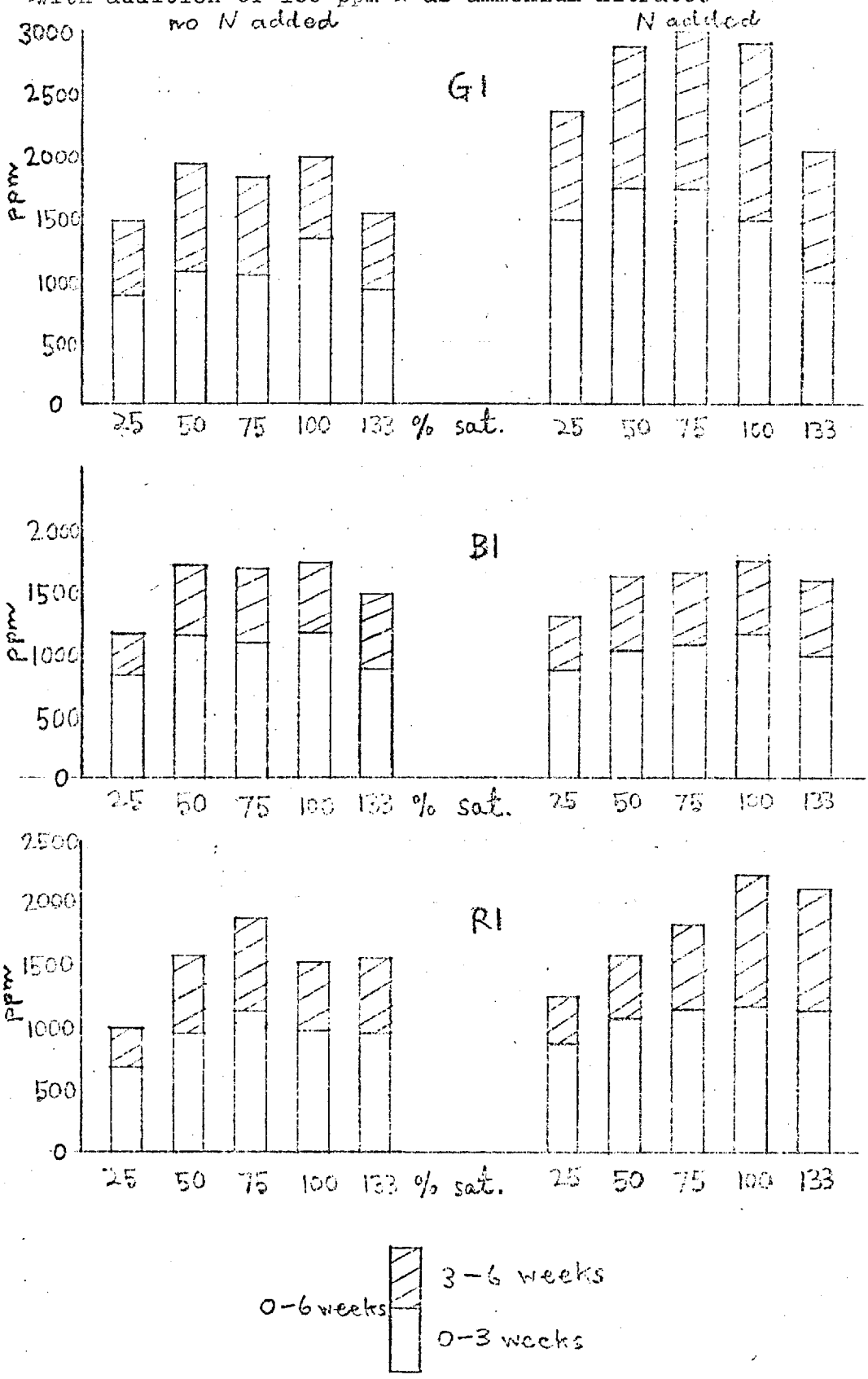
CHAPTER 8 Expt.14 R1 soil Fig.12

Mineral N accumulation during incubation to 6 weeks of R1 soil at varying moisture levels without and with addition of 100 ppm N as ammonium nitrate.



Chap.8 Expts.12, 13, 14 G1, B1, R1 soils Fig.13

Carbon dioxide release during incubation to 6 weeks of G1, B1 and R1 soils at varying moisture levels without and with addition of 100 ppm N as ammonium nitrate.



saturation, with a small but significant increase occurring by 6 weeks but only at 25% saturation. At 100 and 133% saturation there was moderate loss of mineral N by 3 weeks and considerable loss by 6 weeks.

By 3 weeks where no N was added there was no ammonium accumulation at 25% saturation, but it increased with moisture content. By 6 weeks ammonium was lost at 25 to 100% saturation, but there was considerable accumulation at 133%. Where N was added ammonium accumulation by 3 weeks was greater at 100 and 133% than at the lower saturation levels. By 6 weeks ammonium accumulated to a greater extent at 25% than at 133% saturation, but was lost at 50 to 100% saturation.

Where no N was added carbon dioxide release by 3 weeks was slightly lower at 25% saturation than at the higher moisture levels. By 6 weeks carbon dioxide release increased with moisture content to a maximum at 75% saturation, and was somewhat lower at 100 and 133% saturation. Where N was added carbon dioxide release by 3 weeks was only slightly greater at 50 to 133% saturation than at 25% saturation. By 6 weeks carbon dioxide release increased with moisture content to maxima at 100 and 133% saturation.

Where no N was added pH was little affected by incubation at 25 and 50% saturation by 3 weeks, but increased with higher moisture levels. By 6 weeks there was considerable decreases in pH at 75 and 100% saturation, but little change at other moisture levels. Where N was added there was little change in pH by 3 weeks at 25 to 75% saturation, but considerable increases at 100 and 133%. By 6 weeks there was little further change in pH compared with 3 weeks with all treatments.

DISCUSSION OF CHAPTER 8

G1, B1 and R1 soils

Expts. 12, 13 and 14

A comparison of G1 and B1 soils (both slightly alkaline) with respect to the effects of varying moisture contents on mineral N changes and carbon dioxide release during incubation showed that their responses were often similar, but there were some significant differences between the two soils. The acid R1 soil showed considerable differences in responses compared with G1 and B1.

Where no N was added nitrification by 6 weeks was at a maximum at 75% saturation in G1 and B1 and at 75 and 100% saturation in R1. Where N was added nitrification by 6 weeks was at a maximum at 50% saturation in G1 and B1 and at 75% saturation in R1. This suggests that microorganisms responsible for nitrification function better at higher moisture contents in R1 than in G1 and B1. The possibility that nitrification in R1 is due partly to a heterotrophic process must be considered, since autotrophic nitrification is unlikely at 100% saturation. It is likely that heterotrophic nitrifiers are able to function effectively even at the low soil oxygen content occurring at 100% saturation. It may be that these fungi have relatively low oxygen requirements and what little oxygen diffuses into the soil is used for nitrification. This is possible since the ammonifying heterotrophs do not require oxygen.

At 133% saturation (waterlogged soils) when N was added there was complete loss of added nitrate, presumably by denitrification, by 3 weeks from all three soils. This indicates that under these strictly anaerobic conditions the denitrifying organisms multiplied rapidly and were able to cause early loss of all nitrate. The main

difference between G1 and B1 soils with respect to mineral N changes occurred at 100% saturation whether or not N was added. At this moisture level, where there was a possibility of some diffusion of oxygen into the soils, only G1 accumulated nitrate but then only by 3 weeks. With further incubation to 6 weeks nitrate was lost from G1. This suggests that the nitrifying organisms in G1 were active even at 100% saturation in the early stage of incubation but by 6 weeks, as the activity of the nitrifying organisms decreased due to anaerobic conditions, nitrate was lost, possibly through denitrification. By 6 weeks where N was added all the nitrate was lost from B1, about two-thirds from R1 and about one-fifth from G1 soil. The differences were probably due to variations in texture and structure of the soils.

Incubation time also showed up significant differences between the G1 and B1 soils on the one hand and R1 on the other hand. Whereas G1 and B1 showed a fairly similar pattern in mineral N changes due to increasing moisture by 3 and 6 weeks, R1 showed a different response, particularly with respect to changes in nitrate and ammonium. In R1 by 3 weeks nitrate accumulated only at 25 and 50% saturation but not at 75 to 133% saturation. Whereas by 6 weeks there were only moderate increases in nitrate at 25 and 50% saturation, there were considerable increases at 75 and 100% saturation. In fact, at these two higher moisture contents all the nitrification which occurred in R1 did so in the last 3-week period. Ishaque (21) found a similar delay in nitrification during incubation of an acid "Tea" soil (of a similar type to the R1 soil) from Bangladesh in which other experimental data had indicated that heterotrophic nitrification was operative. The lack of any nitrate accumulation at 100% saturation in R1 by 6 weeks where N was added suggests that this level of added ammonium

sulphate inhibited the activity of the heterotrophic nitrifiers present in the soil.

Carbon dioxide release from soil is dependent on the activity of a wide range of types of heterotrophic microorganisms attacking organic materials. The three soils behaved rather differently with respect to changes in carbon dioxide release in relation to soil moisture level. Where N was added carbon dioxide release was greater at 50 to 100% than at 25 and 133% saturation in G1. In B1 carbon dioxide release was lowest at 25% saturation and about the same at the higher moisture levels, whilst in R1 release increased considerably from 25% saturation to higher moisture levels, with a maximum release at 100 to 133% saturation. It is suggested that differences in response among the three soils is probably due to differential effects on the activity of the heterotrophs responsible for the mineralization of carbon.

The increase in pH (0.9 - 1.7 units) at 75 to 133% saturation where no N was added in R1 soil was probably due to the accumulation of ammonium by 3 weeks. By 6 weeks, where most or all of the ammonium at 75 and 100% saturation had disappeared, the expected fall in pH occurred. Where N was added pH increased (1.6 - 1.8 units) only at 100 and 133% saturation due to the fair accumulation of ammonium at these moisture contents.

SUMMARY OF CHAPTER 8

Mineral N changes and carbon dioxide release were determined over 3 and 6 weeks of incubation (30^{o}) of G1 soil (pH 7.6), B1 soil (pH 7.4) and R1 soil (pH 5.2) at moisture levels of 25, 50, 75, 100 and 133% (water-logged) saturation without and with addition of 100 ppm N as ammonium nitrate.

Where no N was added nitrate accumulation by 3 weeks increased with moisture content up to 50 to 75% saturation in G1 and B1 soils. There was some nitrate accumulation in G1 but not in B1 at 100% saturation by 3 weeks and no accumulation in either soil by 6 weeks at 133% saturation. In R1 nitrate accumulation by 3 weeks increased with moisture to 50% saturation, but there was no accumulation at higher moisture contents. By 6 weeks in R1 nitrate accumulation increased with moisture to a maxima at 75 and 100% saturation, but no accumulation occurred at 133%. Where N was added nitrate accumulation in G1 and B1 increased with moisture to a maximum at 50% saturation by 3 and 6 weeks. There was some nitrate accumulation even at 100% saturation in G1 by 3 weeks, but loss of nitrate occurred by 6 weeks at 100 and 133% saturation in G1 and B1. In R1 by 3 weeks there was slight nitrate accumulation only at 50 and 75% saturation. By 6 weeks nitrate accumulation increased with moisture content up to 75% saturation. There was considerable loss of nitrate at 100 and 133% saturation by 3 and 6 weeks.

Changes in mineral N (ammonium plus nitrate N) due to increasing moisture in G1 and B1 soils paralleled those of nitrate. Where no N was added mineral N accumulation was only slightly less or similar to nitrate changes. Where N was added mineral N accumulation was considerably lower than nitrate or there was more loss of mineral N

compared with nitrate at each moisture level. In R1 where no N was added mineral N accumulation increased with moisture level up to a maximum at 133% saturation by 3 and 6 weeks. Where N was added mineral N accumulated to about the same extent at 25 to 75% saturation by 3 and 6 weeks. Where mineral N accumulated it was accounted for almost entirely as ammonium by 3 weeks, but as nitrate by 6 weeks at 50 and 75% saturation, and as ammonium at 25% saturation.

In G1 and B1 changes in ammonium with increasing moisture by 3 and 6 weeks were small after each incubation period whether or not N was added. The main difference was for slightly less loss of ammonium at 100 and 133% saturation than at the lower moisture levels.

At 133% saturation where N was added there was complete loss of added nitrate, presumably by denitrification, by 3 weeks from all three soils, and this loss persisted until 6 weeks. At 100% saturation all the added nitrate was lost by 6 weeks from B1, about 60% from R1 and about 20% from G1.

Changes in carbon dioxide release due to varying moisture content differed with soil type. In G1 it was lower at 25 and 133% saturation than at the intermediate moisture contents. In B1 it was lower at 25% saturation than at the higher moisture contents. In R1 without added N it increased with moisture content to a maximum at 75% saturation and then decreased somewhat at 100 and 133% saturation. In R1 with added N carbon dioxide release increased with moisture to maxima at 100 and 133% saturation.

Results are discussed in relation to the possibility of occurrence of heterotrophic nitrification in the R1 soil.

CHAPTER 9

EFFECTS OF TEMPERATURE (20^{o} to 60^{o}) ON MINERAL NITROGEN CHANGES AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1, B1 AND R1 SOILS ALONE AND TREATED WITH 100 ppm NITROGEN AS AMMONIUM SULPHATE.

Experiment 15 G1 soil

Experiment 16 B1 soil

Experiment 17 R1 soil

CHAPTER 9

Experiment 15

Effects of temperature (20° to 60°) on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of G1 soil alone and treated with 100 ppm nitrogen as ammonium sulphate.

METHODS

The G1 soil was set up for incubation at 50% saturation and at temperatures of 20, 30, 40 50 and 60° without and with addition of 100 ppm N as ammonium sulphate (added in solution in the water used to bring the soils to 50% saturation). Sufficient tubes were set up to allow for analysis initially and after 3 and 6 weeks of incubation. Carbon dioxide release was also determined.

RESULTS

Results for mineral N levels and accumulation and carbon dioxide release are shown in Table 16. Accumulation values for mineral N are shown also in Fig. 14 and carbon dioxide release in Fig. 17.

Where no N was added nitrate accumulation increased with temperature to a maximum at 40° and then decreased to very low levels or nil at 50 and 60° by 3 and 6 weeks. Nitrate accumulation by 3 and 6 weeks at 20 and 30° was similar, but at 40° was greater by 6 than by 3 weeks. Mineralized N accumulated entirely as nitrate at 20 to 40° by 3 and 6 weeks, whilst at 50 and 60° it accumulated almost entirely as ammonium.

Where N was added maximum nitrate accumulated at 30° to about the same extent by 3 and 6 weeks. At all other temperatures nitrate

TABLE 16

Chap. 9 Expt. 15

EFFECTS OF TEMPERATURE (20, 30, 40, 50 and 60°C) ON LEVELS AND ACCUMULATION OF MINERAL NITROGEN AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF G1 SOIL ALONE AND TREATED WITH 100 ppm N AS AMMONIUM SULPHATE (N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

N added	NH_4-N	NO_3-N	min-N	pH
0	5.9	12.0	17.9	7.5
N	48.3	11.0	59.3	7.4

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
Temp °C	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
20	0	1.6	29.3	30.9	7.9	- 4.3	17.3	13.0
"	N	27.2	12.0	39.2	7.6	-21.1	1.0	-20.1
30	0	0.3	42.0	42.3	7.9	- 5.6	30.0	24.4
"	N	1.1	75.9	77.0	7.4	-47.2	64.9	17.7
40	0	1.3	52.0	53.3	7.7	- 4.6	40.0	35.4
"	N	19.9	20.7	40.6	7.9	-28.4	9.7	-18.7
50	0	15.4	16.8	32.2	8.3	9.5	4.8	14.3
"	N	32.9	12.0	44.9	8.2	-15.4	1.0	-14.4
60	0	22.4	12.2	34.6	8.3	16.5	0.2	16.7
"	N	38.7	10.4	49.1	8.3	- 9.6	-0.6	-10.2
		After 6 weeks incubation						
20	0	0.6	30.9	31.5	8.1	- 5.3	18.9	13.6
"	N	15.4	23.0	38.4	7.8	-32.9	12.0	-20.9
30	0	0.6	42.8	43.4	8.1	- 5.3	30.8	25.5
"	N	0.3	83.7	84.0	7.8	-48.0	72.7	24.7
40	0	0.9	66.3	67.2	8.2	- 5.0	54.3	49.3
"	N	16.2	30.6	46.8	8.0	-32.1	19.6	-12.5
50	0	23.8	12.6	36.4	8.4	17.9	0.6	18.5
"	N	36.4	12.6	49.0	8.3	-11.9	1.6	-10.3
60	0	27.4	11.9	39.3	8.3	21.5	-0.1	21.4
"	N	44.8	11.2	56.0	8.3	- 3.5	0.2	- 3.3

L.S.D ($P < 0.05$) NH_4-N 3.5, NO_3-N 4.0 and min-N 5.6

TABLE 16 (continued)

CARBON DIOXIDE RELEASE (Weeks)

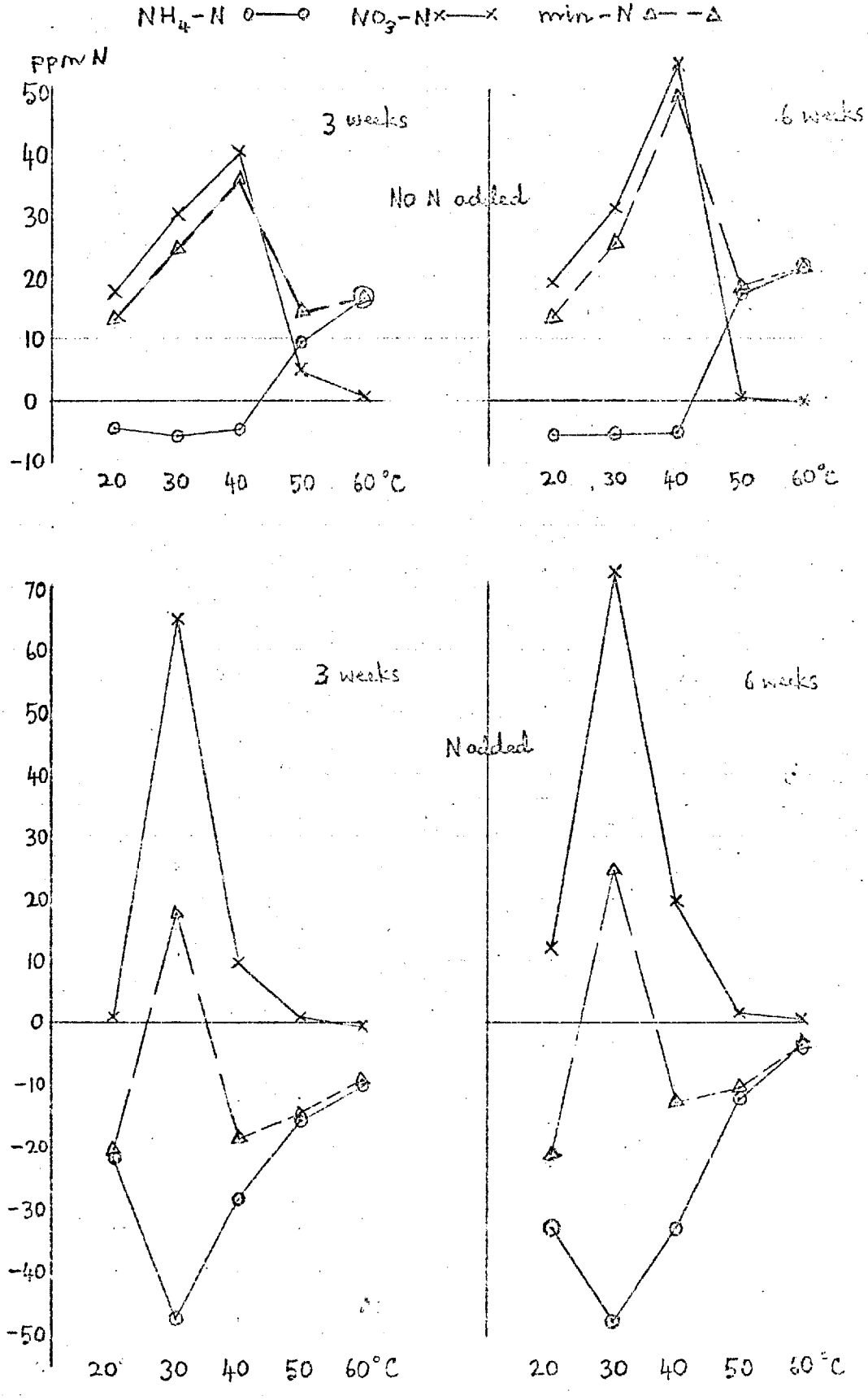
(Results are in ppm on dry soil basis)

Temp °C	N added	0-3	3-6	0-6
20	0	860	690	1550
"	N	900	560	1460
30	0	1565	755	2320
"	N	1430	820	2250
40	0	1830	1085	2915
"	N	2150	1000	3150
50	0	2475	710	3185
"	N	2310	1030	3340
60	0	3515	1125	4640
"	N	3235	970	4205

L.S.D ($P < 0.05$) 205

CHAPTER 9 Expt.15 Fig.14 G1 soil

Effect of temperature (20° to 60°) on mineral N accumulation during incubation to 6 weeks of G1 soil alone and treated with 100 ppm N as ammonium sulphate.



accumulation was relatively low. At 20, 50 and 60° there was no nitrate accumulation by 3 weeks, nor was there any at 50 and 60° by 6 weeks, but there was slight further nitrate accumulation by 6 weeks at 20 and 40°. There was fair loss of ammonium at all temperatures by 3 and 6 weeks, with maximum loss at 30°, and the loss decreased with further increasing temperature. Mineral N accumulated only at 30° by 3 and 6 weeks.

Carbon dioxide release increased with temperature to a maximum at 60°. Addition of N decreased carbon dioxide release at 60°, but had no effect at the lower temperatures. The proportion of the total carbon dioxide which was released during the first 3 weeks increased with incubation temperature.

Where no N was added pH increased at all temperatures, but particularly at 50 and 60°. Where N was added there was no or slight increases in pH at 20 and 30° and moderate increases at 40 to 60°. There were negligible changes in pH between 3 and 6 weeks whether or not N was added.

CHAPTER 9

Experiment 16

Effects of temperature (20° to 60°) on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of B1 soil alone and treated with 100 ppm N as ammonium sulphate.

METHODS

As described in Expt. 15 except that the B1 soil was used.

RESULTS

Results for mineral N levels and accumulation and carbon dioxide release are shown in Table 17. Accumulation values for mineral N are shown also in Fig. 15 and carbon dioxide release in Fig. 17.

Where no N was added nitrate accumulation increased moderately with temperature to a maximum at 40° and decreased to nil at 50 and 60° both after 3 and 6 weeks. Most of the nitrate which accumulated did so during the first 3 weeks. Mineralized N accumulated entirely as nitrate at 20 to 40° and entirely as ammonium at 50 and 60°.

Where N was added maximum nitrate accumulated at 30° by 3 and 6 weeks. There was slight accumulation of nitrate at 20°, moderate accumulation at 40° and no accumulation at 50 and 60°. Where nitrate accumulated it was only slightly greater by 6 than by 3 weeks. There was fair loss of ammonium at all temperatures, particularly at 30 and 40°, by 3 weeks, with little further change by 6 weeks. Mineral N accumulation occurred only by 6 weeks and then only at 30°.

Carbon dioxide release increased with temperature of incubation to 40°, decreased slightly to 50° and then increased to a maximum at 60° by 3 and 6 weeks. Most of the carbon dioxide was released during the first 3 weeks. Addition of N had no effect on carbon dioxide release by 3 or 6 weeks.

TABLE 17

Chap. 9 Expt. 16

EFFECTS OF TEMPERATURE (20, 30, 40, 50 AND 60°C) ON LEVELS AND ACCUMULATION OF MINERAL NITROGEN AND CARBON DIOXIDE RELEASE DURING INCUBATION TO 6 WEEKS OF B1 SOIL ALONE AND TREATED WITH 100 ppm N AS AMMONIUM SULPHATE

NITROGEN CHANGES

(Results are in ppm on dry soil basis)

Initial values

N added	NH_4-N	NO_3-N	min-N	pH
0	3.9	5.5	9.4	7.2
N	60.6	4.5	65.1	7.0

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
Temp °C	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
20	0	2.3	30.5	32.8	7.0	- 1.6	25.0	23.4
"	N	31.7	10.0	41.7	6.9	-28.9	5.5	-23.4
30	0	1.3	38.7	40.0	6.9	- 2.6	33.2	30.6
"	N	2.0	65.2	67.2	6.4	-58.6	60.7	2.1
40	0	3.8	42.3	46.1	6.9	- 0.1	36.8	36.7
"	N	10.9	28.3	39.2	6.8	-49.7	23.8	-25.9
50	0	17.5	7.4	24.9	7.3	13.6	1.9	15.5
"	N	28.9	4.8	33.7	7.1	-31.7	0.3	-31.4
60	0	18.0	7.2	25.2	7.3	14.1	1.7	15.8
"	N	26.3	4.0	30.3	7.1	-34.3	-0.5	-34.8
		After 6 weeks incubation						
20	0	0.5	36.0	36.5	7.0	- 3.4	30.5	27.1
"	N	30.1	16.1	46.2	6.9	-30.5	11.6	-18.9
30	0	0.7	42.4	43.1	6.9	- 3.2	36.9	33.7
"	N	1.6	72.6	74.2	6.4	-59.0	68.1	9.1
40	0	0.3	49.0	49.3	6.9	- 3.6	43.5	39.9
"	N	13.0	36.4	49.4	6.8	-47.6	31.9	-15.7
50	0	16.7	6.4	23.1	7.4	12.8	0.9	13.7
"	N	31.5	4.6	36.1	7.1	-29.1	0.1	-29.0
60	0	20.7	6.1	26.8	7.4	16.8	0.6	17.4
"	N	34.0	4.0	38.0	7.1	-26.6	-0.5	-27.1

L.S.D ($P < 0.05$) NH_4-N 2.9, NO_3-N 3.4, min-N 4.0

TABLE 17 (continued)

CARBON DIOXIDE RELEASE (Weeks)

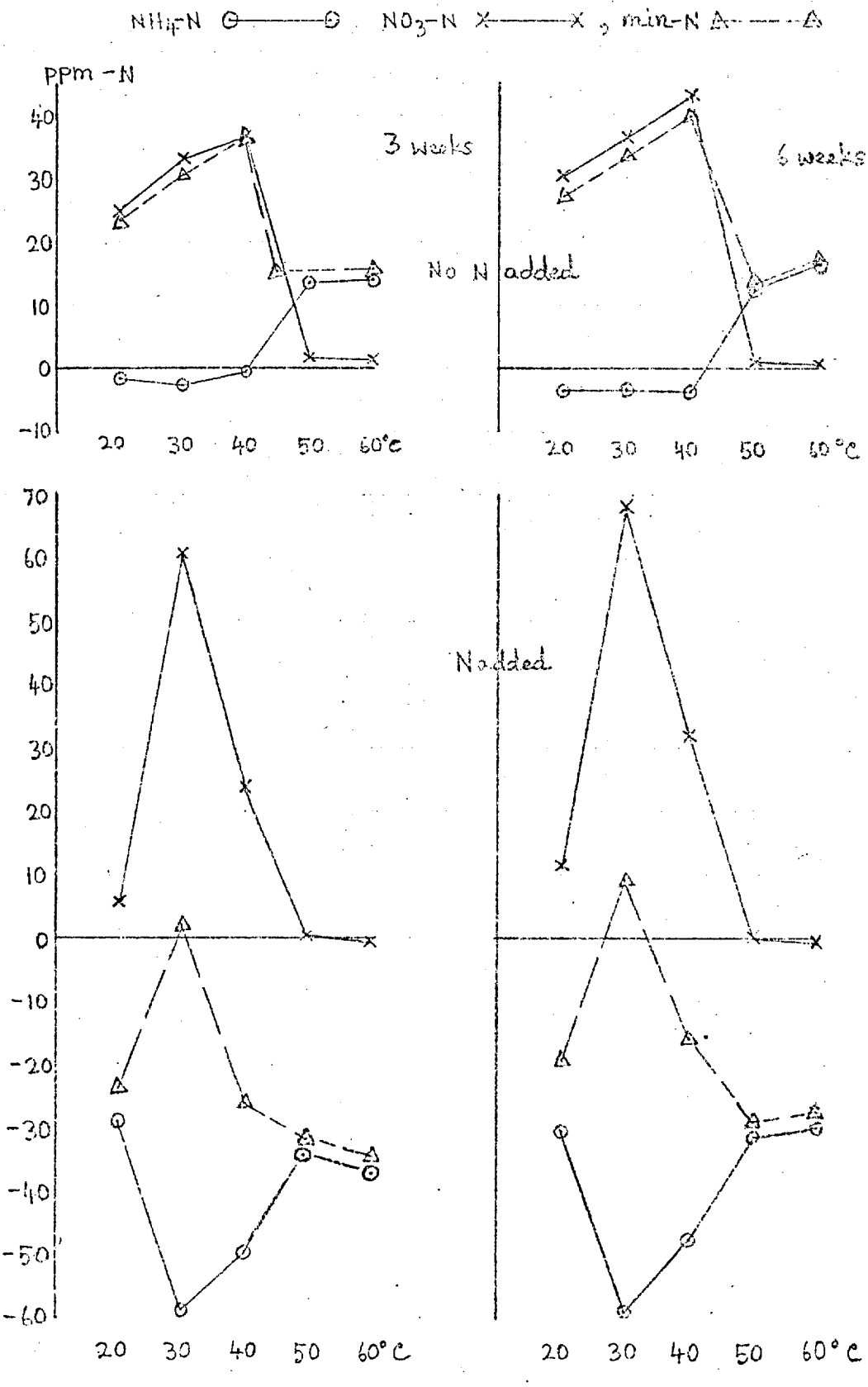
(Results are in ppm on dry soil basis)

Temp °C	N added	0-3	3-6	0-6
20	0	875	410	1285
"	N	835	425	1260
30	0	1170	570	1740
"	N	1270	580	1850
40	0	1830	595	2425
"	N	1680	770	2450
50	0	1750	490	2240
"	N	1775	530	2305
60	0	2180	690	2870
"	N	2225	600	2825

L.S.D ($P < 0.05$) 160

CHAPTER 9 Expt.16 Fig.15 B1 soil

Effect of temperature (20° to 60°) on mineral N accumulation during incubation to 6 weeks of B1 soil alone and treated with 100 ppm N as ammonium sulphate



Where no N was added there was negligible change in pH at 50 and 60^{o} and slight decreases at 20 to 40^{o}. Where N was added pH decreased by 0.6 units at 30^{o}, by 0.2 units at 20 and 40^{o}, but was unaffected at 50 and 60^{o}. There was virtually no difference in pH between 3 and 6 weeks of incubation whether or not N was added.

CHAPTER 9

Experiment 17

Effects of temperature (20° to 60°) on mineral nitrogen changes and carbon dioxide release during incubation to 6 weeks of R1 soil alone and treated with 100 ppm N as ammonium sulphate.

METHODS

As described in Expt. 15 except that the R1 soil was used.

RESULTS

Results for mineral N levels and accumulation and carbon dioxide release are shown in Table 18. Accumulation values for mineral N are shown also in Fig. 16 and for carbon dioxide release in Fig. 17.

Where no N was added nitrate accumulation by 3 and 6 weeks increased with temperature to a maximum at 30°, but declined with further increasing temperature to nil at 50 and 60°. Nitrate accumulation was greater by 6 than by 3 weeks, but only at 30 and 40°. By 3 and 6 weeks mineralized N increased with temperature to 40°, was not further affected or was decreased at 50°, and reached a maximum at 60°. Mineralized N accumulated mainly as nitrate at 20 and 30°, mainly as ammonium at 40° and entirely as ammonium at 50 and 60°. Mineralized N by 6 weeks was greater than by 3 weeks at all temperatures, but particularly at 60°.

Where N was added nitrate accumulated only at 30° and accumulation was greater by 6 than by 3 weeks. Mineralized N by 3 and 6 weeks increased with temperature to 40°, but was not further affected at 50 and 60°. By 6 weeks mineralized N was greater at 40, 50 and 60° than by 3 weeks.

TABLE 18

Chap. 9 Expt. 17

EFFECTS OF TEMPERATURE (20, 30, 40, 50 and 60°C) ON LEVELS AND ACCUMULATION OF MINERAL NITROGEN AND CARBON DIOXIDE RELEASE DURING INCUBATION OF R1 SOIL ALONE AND TREATED WITH AMMONIUM SULPHATE (100 ppm N)

NITROGEN CHANGES

(Results are given in ppm on dry soil basis)

Initial values

N added	NH_4-N	NO_3-N	min-N	pH
0	10.6	4.4	15.0	5.0
N	105.0	3.5	108.5	4.9

		L E V E L S				ACCUMULATION		
		After 3 weeks incubation						
Temp °C	N added	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
20	0	20.6	10.1	31.7	5.0	10.0	5.7	15.7
"	N	114.0	3.9	117.9	5.0	9.0	0.4	9.4
30	0	15.4	25.2	40.6	4.9	4.8	20.8	25.6
"	N	113.4	11.2	124.6	4.9	8.4	7.7	16.1
40	0	31.6	16.4	48.0	5.2	21.0	11.0	33.0
"	N	123.2	5.7	128.9	5.2	18.2	2.2	20.4
50	0	44.1	1.4	45.5	5.6	33.5	- 3.0	30.5
"	N	126.6	2.5	129.1	5.3	21.6	- 1.0	20.6
60	0	56.0	1.4	57.4	5.6	45.4	- 3.0	42.4
"	N	124.1	2.3	126.4	5.3	19.1	- 1.2	17.9
		After 6 weeks incubation						
20	0	21.8	12.9	34.7	5.0	11.2	8.5	19.7
"	N	113.1	5.6	118.7	5.0	8.1	2.1	10.2
30	0	8.7	36.2	44.9	4.7	-1.9	31.8	29.9
"	N	100.8	27.5	128.3	4.7	-4.2	24.0	19.8
40	0	41.4	25.2	66.6	5.1	30.8	20.8	51.6
"	N	140.0	5.6	145.6	5.3	35.0	2.1	37.1
50	0	56.0	2.8	58.8	5.7	45.4	- 1.6	43.8
"	N	142.2	3.4	145.6	5.4	37.2	- 0.1	37.1
60	0	79.5	2.3	81.8	5.7	68.9	- 2.1	66.8
"	N	143.5	2.5	146.0	5.3	38.5	- 1.0	37.5

L.S.D ($P < 0.05$) NH_4-N 6.1, NO_3-N 2.3, min-N 6.7

TABLE 18 (continued)

CARBON DIOXIDE RELEASE (Weeks)

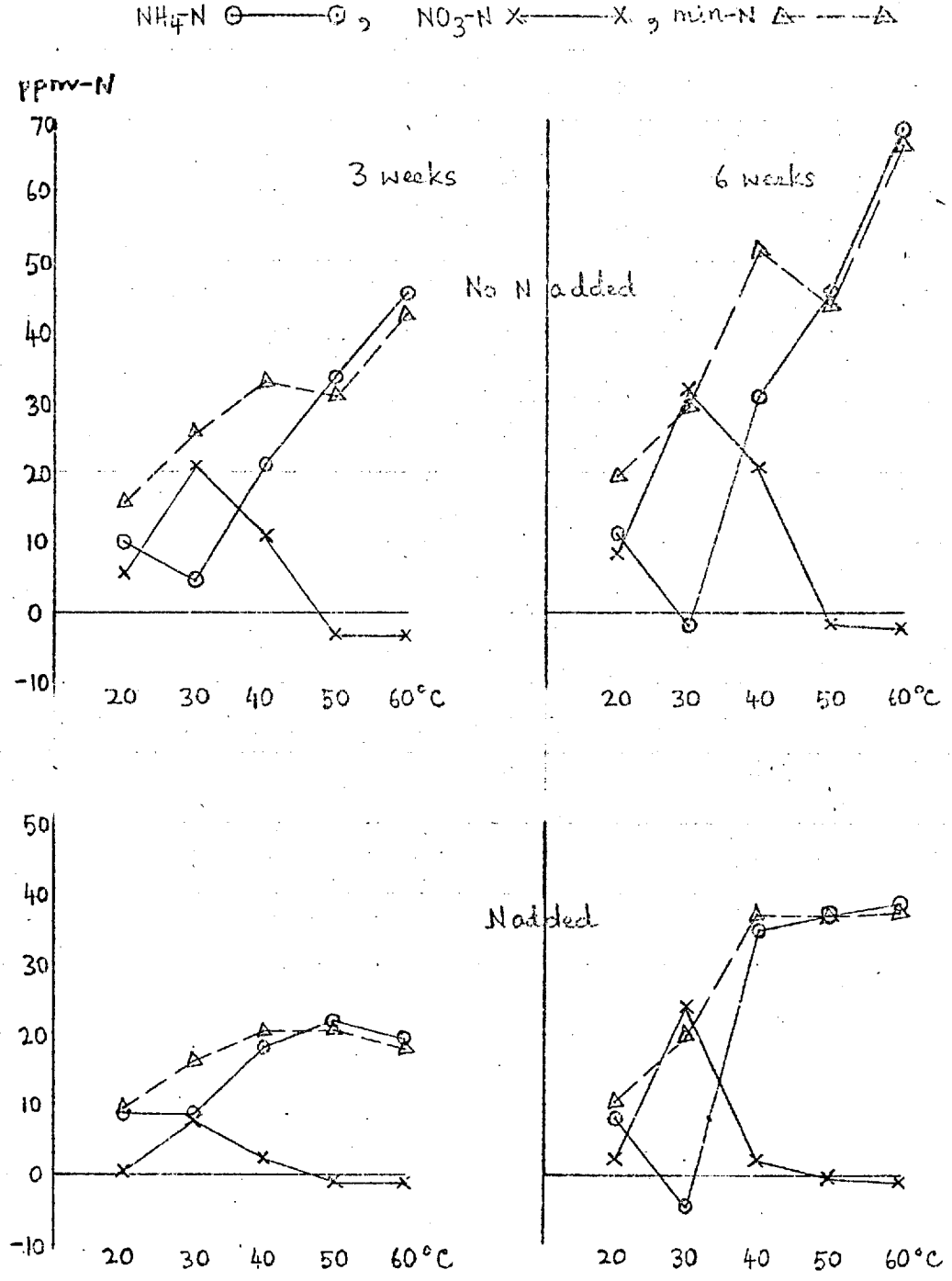
(Results are in ppm on dry soil basis)

Temp °C	N added	0-3	3-6	0-6
20	0	900	410	1310
"	N	500	320	820
30	0	1220	515	1735
"	N	1090	665	1755
40	0	1100	715	1815
"	N	1165	440	1605
50	0	1035	395	1430
"	N	770	315	1085
60	0	1165	500	1665
"	N	490	356	846

L.S.D ($P < 0.05$) 165

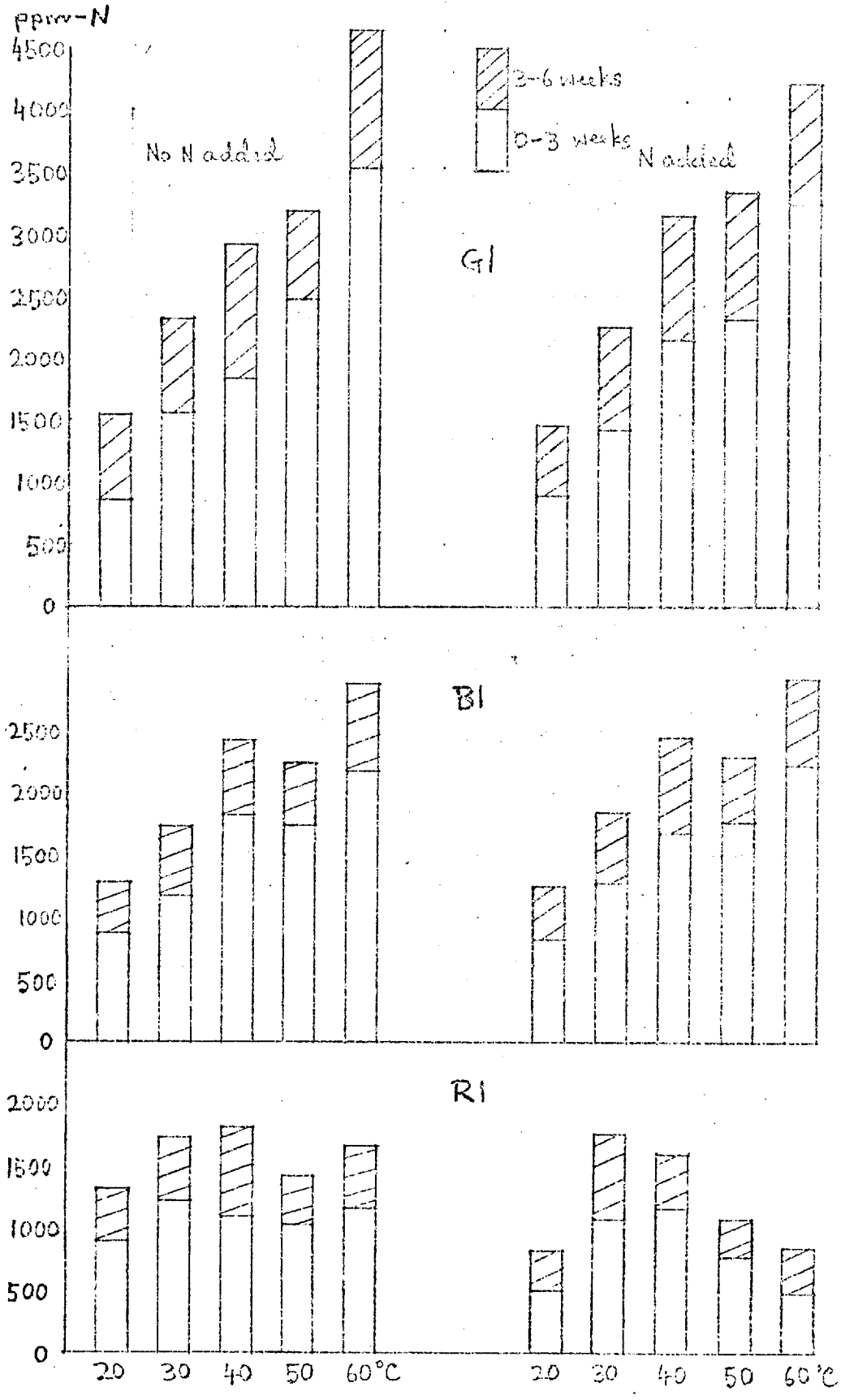
CHAPTER 9 Expt.17 Fig.16 R1 soil

Effect of temperature (20° to 60°) on mineral N accumulation during incubation to 6 weeks of R1 soil alone and treated with 100 ppm N as ammonium sulphate.



CHAPTER 9 Expts.15, 16, 17 Fig.17 G1, B1, R1 soils

Effect of temperature (20° to 60°) on carbon dioxide release during incubation to 6 weeks of G1, B1 and R1 soils alone and treated with 100 ppm N as ammonium sulphate.



Where no N was added carbon dioxide release increased with temperature to 30 and 40°, decreased to 50° and increased slightly again at 60°. Where N was added carbon dioxide release increased to a maximum at 30°, but decreased with further increasing temperature until at 60° it was the same as at 20°. Addition of N decreased carbon dioxide release at 20, 40, 50 and 60°.

Where no N was added pH was little affected at 20 and 30°, but was increased at higher temperatures by 0.2 - 0.6 units. Where N was added pH was barely affected at 20 and 30°, but increased with further increase in temperature by 0.3 - 0.4 units. Addition of N had little effect on pH changes at each incubation temperature.

DISCUSSION OF EXPERIMENTS 15, 16 AND 17

The responses of G1 and B1 soils to varying temperatures of incubation were generally similar, although there were some significant differences between the two soils. Where no N was added the greater increase in both nitrification and N mineralization with increasing temperature to 40° in G1 than in B1 suggests that the microorganisms concerned with these processes were more responsive to increasing temperature in G1 than in B1. The accumulation of mineralized N entirely as nitrate in both these soils up to 40° suggests that even at this temperature nitrification was not being limited. The literature (84-99) indicates that maximum nitrification in soils ranges from 25° to 37°, so that the results obtained with G1 and B1 indicate a slightly higher optimum temperature than usual for nitrification.

The occurrence of maximum nitrification at 40° where no N was added compared with 30° where N was added in both G1 and B1 soils may be due to some loss of ammonia by volatilization. It is known that ammonia volatilization from soils increases with temperature (146-152) and addition of ammonium sulphate. In addition, the low nitrification in G1 and B1 at 40° where N was added may have been due to a toxic effect of ammonium on nitrification. In the R1 soil on the other hand nitrification was at a maximum at 30° whether or not N was added. In R1 addition of ammonium resulted in decreased nitrification at 20 to 40°. It is likely that heterotrophic nitrification is operative in R1 and that addition of ammonium inhibited the process, as was also shown by Ishaque (21) in an acid tea soil from Bangladesh.

The loss of ammonium at 20° in both G1 and B1 soils by 3 and 6 weeks is probably due to immobilization, since ammonia volatilization is unlikely at this low temperature and in addition the very low

nitrification at this temperature compared with 30° indicates that nitrification is negligible at 20° in the presence of added ammonium. On the other hand at 30° in both B1 and G1 loss of ammonium was accounted for entirely as increased nitrate. At 40 to 60° loss of ammonium was not accounted for as increased nitrate. This is probably due to the effects of these higher temperatures inhibiting nitrification in the presence of added ammonium. In addition immobilization of ammonium and volatilization of ammonia may also have accounted in part for these results. The high rate of release of carbon dioxide at the higher temperatures from G1 and B1 suggests that very active decomposition of organic materials in the soils was occurring and the heterotrophs responsible for this decomposition utilized some of the added ammonium.

In G1 and B1 where no N was added mineralized N (ammonium plus nitrate accumulation) increased with temperature up to 40° but declined somewhat at 50 and 60° and mineralized N accumulated entirely as ammonium at the two higher temperatures. This decline is probably due to immobilization of ammonium and/or volatilization of ammonia at these higher temperatures in these two slightly alkaline soils. In the R1 soil on the other hand there was a general increase in N mineralization up to the highest temperature of 60°. In this acid soil it is unlikely that any volatilization of ammonia occurred. In addition since carbon dioxide release from R1 at 50 and 60° was little different compared with the lower temperatures, this suggests that immobilization of N at the higher temperatures was no greater than at the lower temperatures.

At all temperatures, but particularly at 40 to 60°, addition of ammonium decreased N mineralization in R1, suggesting some inhibitory effect of ammonium, particularly at the higher temperatures. This is correlated with a decline in carbon dioxide release in R1 with increasing

temperature from 30 to 60°. It appears that in R1, in contrast to G1 and B1, the heterotrophs responsible for the decomposition of organic materials are sensitive to addition of ammonium N at the higher temperatures.

SUMMARY OF CHAPTER 9

Experiments 15, 16 and 17

The effects of varying temperatures (20, 30, 40, 50 and 60°) on mineral N changes and carbon dioxide release during incubation (at 50% saturation) to 6 weeks of G1, B1 and R1 soils alone and treated with 100 ppm N as ammonium sulphate were studied.

Where no N was added nitrification and N mineralization in G1 and B1 increased with temperature up to 40°. Nitrification decreased to a low level or nil, whilst N mineralization decreased somewhat at 50 and 60°. In R1 nitrification increased to a maximum at 30°, decreased somewhat to 40° and was absent at 50 and 60°. In G1 and B1 N mineralization was accounted for entirely as nitrate up to 40°, but almost entirely as ammonium at 50 and 60°. In R1 N mineralization increased with temperature up to 40-50° and increased even more at 60°. N mineralization in R1 was accounted for largely as nitrate by 3 weeks and entirely as nitrate by 6 weeks at 30°, as both ammonium and nitrate at 20 and 40° and entirely as ammonium at 50 and 60°.

Where N was added nitrification was increased to a much greater extent in G1 and B1 at 30° than at the other temperatures, but there was no nitrification at 50 and 60°. There was moderate N mineralization, but only at 30°, in G1 and B1. In R1 N mineralization increased with temperature up to 40° and was little further affected at 50 and 60°, whilst there was some nitrification, but only at 30°.

In G1 and B1 soils carbon dioxide release increased with temperature to a maximum at 60°, and the rate of increase due to temperature was greater in G1 than in B1. Addition of ammonium sulphate in general had little effect on carbon dioxide release at any

temperature. In R1 where no N was added carbon dioxide release increased slightly with temperature up to 30-40°, decreased slightly by 50° and increased slightly again by 60°. Where N was added carbon dioxide release increased moderately with temperature to 30°, but declined with further increase in temperature by 60°, to about the same level as at 20°.

Results are discussed in relation to possible loss of ammonia by volatilization, immobilization of mineral N and, in the R1 soil, the possible occurrence of heterotrophic nitrification.

CHAPTER 10

MISCELLANEOUS EXPERIMENTS

Experiment 18

Fixation of ammonium by the clay fractions of G3, B3 and R2 soils, and mineralization of fixed ammonium during incubation.

Experiment 19

Denitrification during waterlogged incubation to 6 weeks of G1, B1 and R1 soils treated with 2% straw and 500 ppm N as potassium nitrate.

Experiment 20

Effect of period of air-dry storage on mineral N changes and mineralizable N and carbon dioxide release during incubation of G3, B3 and R2 soils.

CHAPTER 10

EXPERIMENT 18

Fixation of ammonium by the clay fractions of G3, B3 and R2 soils, and mineralization of fixed ammonium during incubation.

METHODS

100 g of each soil was shaken with 1 litre of 0.1N sodium hydroxide for 24 hours to disperse the clay. After standing for 5½ hours the top 10 cm of the suspension was transferred to a beaker and just neutralized with hydrochloric acid. 50g of calcium chloride was stirred in to coagulate the clay. After settling, the supernatant liquid was decanted off and the remaining suspension was boiled with four successive portions of hydrogen peroxide to destroy organic material. The residual clay was then filtered off, washed and then dried and ground to pass a 1 mm sieve. Each of the clays were then leached with N-ammonium acetate (pH 7.0) and the excess ammonium acetate washed out with 70% aqueous alcohol. The ammonium-saturated clays were then dried at 100° for 24 hours to induce fixation of ammonium. The clays were then leached with N-calcium chloride to remove exchangeable ammonium and then with 0.2% calcium sulphate to remove chloride and finally air-dried at room temperature. The calcium-saturated clays now contained ammonium only in fixed form. Fixed ammonium was determined in each of the clays by extraction with N-hydrofluoric acid-N-hydrochloric acid (21). For incubation 0.5g portions of the clays were mixed with 8.5g of acid-washed silver sand and 1g of the respective original soil as inoculant to supply microorganisms. These mixtures were incubated at 30° and 50% saturation for 3 and 6 weeks. To correct for ammonium and nitrate

production from the 1g of soil inoculum, blanks containing 1g of soil and 9g of sand were also incubated.

RESULTS AND DISCUSSION

Table 19 shows results for (i) the extent of fixation of ammonium-N by the clay fractions of G3, B3 and R2 soils and (ii) the extent of mineralization (conversion of fixed ammonium to nitrate and exchangeable ammonium) during incubation. Allowances have been made for the mineral N accumulating in the controls.

The level of fixed ammonium-N in G3 clay was 426 ppm, in B3 clay 252 ppm and in R2 clay 44 ppm. The differences in ammonium fixation among the three clays is due to the differences in the types of clay present (see Chapter 2, "Clay Mineralogy"). The G3 and B3 clays, with high ammonium fixing capacities, were high in illite, interstratified smectite-illite and vermiculite, all of which have high fixing capacities for ammonium. The relatively low fixation of ammonium by the R2 soil was probably due mainly to the presence of vermiculite, but the mica and kaolinite, which were also present in high proportions, have low fixing capacities, resulting in relatively low overall fixation by the R2 clay.

During the incubation of G3 and B3 (mixed with sand and soil inoculant) most of the mineralization of fixed ammonium occurred during the first 3 weeks and was accounted for entirely as nitrate. By 6 weeks some further fixed ammonium was mineralized and was also accounted for as nitrate. In R2, on the other hand, all the mineralized ammonium by 3 and 6 weeks was accounted for as ammonium, and here again most of the ammonium was mineralized during the first 3 weeks. By 6 weeks 100% of the fixed ammonium was mineralized in B3, 89% in R2 and 77% in G3. It is seen that the % mineralization of

TABLE 19

Chap. 10 Expt. 18

FIXATION OF AMMONIUM BY THE CLAY FRACTIONS OF G3, B3 AND R2 SOILS, AND MINERALIZATION OF FIXED AMMONIUM DURING INCUBATION TO 6 WEEKS

(Results are in ppm on dry clay basis)

The G3 clay contains 426 ppm, the B3 clay 252 ppm and the R2 clay contains 44 ppm of fixed ammonium-N.

MINERALIZATION AND NITRIFICATION OF INITIAL FIXED AMMONIUM AFTER 3 AND 6 WEEKS OF INCUBATION

	3 weeks incubation			6 weeks incubation		
Soil	NH_4-N	NO_3-N	min-N	NH_4-N	NO_3-N	min-N
G3	0	308	308	0	330	330
B3	0	207	207	0	252	252
R2	28	0	28	39	0	39

PERCENTAGE OF FIXED AMMONIUM CONVERTED TO EXCHANGEABLE MINERAL NITROGEN

	3 weeks incubation			6 weeks incubation		
Soil	NH_4-N	NO_3-N	min-N	NH_4-N	NO_3-N	min-N
G3	0	72	72	0	77	77
B3	0	82	82	0	100	100
R2	64	0	64	89	0	89

fixed ammonium was not related to the extent of fixation among the three soil clays. The accumulation of mineralized N entirely as nitrate in the G3 and B3 clays would be expected because of the slightly alkaline pH of these mixtures. However, the absence of any nitrification of fixed ammonium in the R2 soil is difficult to explain. It may be that the nitrifying organisms present in the acid inoculant did not survive the neutral pH, due to the Ca-saturated clay, in the clay-sand-inoculant mixture. However, some mechanism (chemical and/or microbiological) was operative in converting fixed to exchangeable ammonium.

SUMMARY

The clay fractions (less than 0.002 mm) were separated from G3, B3 and R2 soils by dispersion and sedimentation and after destruction of organic material the clays were saturated with ammonium and dried at 100^{o} for 24 hours to induce fixation of ammonium. The G3 clay fixed 426 ppm, the B3 clay 252 ppm and the R2 clay 44 ppm of ammonium-N.

0.5g portions of each clay were mixed with 8.5g of sand and 1g of respective original soil as inoculant and incubated for 6 weeks at 30^{o} and 50% saturation. By 6 weeks of incubation 100% of the fixed ammonium was mineralized in B3 and 77% in G3; mineralized N accumulated entirely as nitrate. In R2, 89% of the fixed ammonium was mineralized and accumulated entirely as ammonium.

CHAPTER 10

EXPERIMENT 19

Denitrification during waterlogged incubation to 6 weeks of G1, B1 and R1 soils treated with 2% straw and 500 ppm N as potassium nitrate.

METHODS

2g portions of G1, B1 and R1 soils were mixed with 2% w/w finely ground straw and placed in 50 ml Kjeldhal flasks. 500 ppm N as potassium nitrate, on the soil basis, was added dissolved in 2 ml of water, which produced a waterlogged condition. The flasks were closed with corks and incubated for 3 and 6 weeks at 30°. Initially and after each incubation period residual nitrate was reduced to ammonium by boiling with iron powder and 2N sulphuric acid. Then concentrated sulphuric acid, potassium sulphate (to raise the boiling point) and copper sulphate catalyst were added, and the mixture digested in the usual way to convert all organic N compounds to ammonium. The ammonium was determined by steam distillation, after addition of excess sodium hydroxide, into 2% boric acid and titrated with 0.1N hydrochloric acid using a methyl red - bromocresol green indicator.

RESULTS AND DISCUSSION

Table 20 shows (i) total N initially and after 3 and 6 weeks of incubation, (ii) loss of nitrate in ppm after 3 and 6 weeks and (iii) percent added nitrate lost after 3 and 6 weeks.

By 3 weeks of incubation the G1 and B1 soils showed considerably greater loss of nitrate than did R1. During 3-6 weeks G1 and B1 showed small further losses of nitrate, whilst R1 showed a considerable

TABLE 20

Chap. 10 Expt. 19

DENITRIFICATION DURING WATER LOGGED INCUBATION TO 6 WEEKS OF G1, B1 AND R1 SOILS TREATED WITH 2% STRAW AND 500 ppm N AS POTASSIUM NITRATE

(Results are in ppm on dry soil basis)

(i)

Soil	Total N Initially	Total N after 3 wk. incub.	Total N after 6 wk. incub.
G1	1505	1115	1078
B1	1474	1078	1054
R1	1428	1311	977

L.S.D ($P < 0.05$) 53

	(ii)		(iii)	
Soil	(a)	(b)	(c)	(d)
G1	390	427	78.0	85.4
B1	396	420	79.2	84.0
R1	117	451	23.4	90.2

(a) NO_3-N lost after 3 weeks incubation (ppm)

(b) NO_3-N lost after 6 weeks incubation (ppm)

(c) % added NO_3-N lost after 3 weeks incubation

(d) % added NO_3-N lost after 6 weeks incubation

loss, so that by 6 weeks loss of nitrate was similar from all three soils. It is likely that the R1 soil, because of its low pH and because it hardly ever becomes waterlogged (and when it does so it drains and dries rapidly) contained initially a very low population of denitrifying bacteria compared with G1 and B1 soils, and this could account for the relatively low denitrification in R1 during the first 3-week period. However, during 3-6 weeks the organisms multiplied rapidly so that by 6 weeks denitrification from R1 was as high as from G1 and B1. Bacterial denitrification under acid conditions is slow (1), but chemical denitrification can occur by reaction of nitrite (produced by reduction of nitrate) with ammonium followed by decomposition of ammonium nitrite to nitrogen and water. In addition spontaneous decomposition of nitrite to nitric oxide can occur.

The fact that there was not complete denitrification of added nitrate from any of the soils even by 6 weeks suggests that some of the nitrate may have been immobilized by the microorganisms decomposing the straw and was locked up in microbial tissue.

SUMMARY

The extent of loss of nitrate by denitrification during waterlogged incubation to 6 weeks of G1, B1 and R1 soils treated with 2% straw and 500 ppm N as potassium nitrate was studied. By 3 weeks the G1, B1 and R1 soils lost 78.0, 79.2 and 23.4% and by 6 weeks 85.4, 84.0 and 90.2% respectively of the added nitrate.

CHAPTER 10

EXPERIMENT 20

Effect of period of air-dry storage on (i) mineral nitrogen levels and (ii) mineralizable nitrogen and carbon dioxide release during incubation of G3, B3 and R2 soils.

The advantage of storing soil samples in air-dry over storing them in moist condition is obvious. If an experiment has to be repeated with a soil sample it might be thought that no changes would occur due to the period of air-dry storage, whereas this would not be the case if it was stored in moist condition. However, Birch (234) working with African soils found that mineralizable N during incubation increased with period of air-dry storage to 15 weeks. On the other hand Gasser (180), using English soils, found that period of air-dry storage in general had little effect on mineralizable N with storage periods of up to 16 weeks. Cornfield (181), also using English soils, found that although there were some differences among eight soils in mineralizable N between 1 and 12 weeks of storage, there were only slight differences between the averages of these two periods in mineralizable N. Average nitrate accumulation, however, was somewhat greater after 1 than after 12 weeks of storage.

METHODS

Dry samples of G3, B3 and R2 soils were placed in pots, wetted to 50% saturation and maintained around this moisture content for 2 weeks. This was done in order to bring the soils more or less to their original moist microbiological activity. The soils were then air-dried and placed in bottles with screw-on lids. Mineral N levels and mineralizable N (3 weeks incubation at 30^{o} and 50% saturation)

were determined initially and after 16, 32, 52 and 70 weeks of air dry storage at room temperature (17-23°).

RESULTS AND DISCUSSION

Table 21 shows (i) mineral N and (ii) mineralizable N and (iii) carbon dioxide release after various storage periods. Figure 18 shows mineral N levels and Figure 19 mineralizable N after various storage periods.

With each soil mineral N levels due to period of air-dry storage were affected to relatively small extents, even though some of the differences were significant. Changes in ammonium levels due to storage period were also relatively small, although there was a trend for slight increases to 32 weeks followed by slight decreases to 70 weeks. Changes in ammonium roughly paralleled those of mineral N. There were no changes in nitrate with up to 32 weeks storage, but a slight increase with further storage.

Mineralizable N changes were similar in G3 and B3 soil, increasing somewhat to 32 weeks and declining to 52 and 70 weeks. With R2 soil there was a decrease in mineralizable N to 16 weeks, an increase to 32 weeks, followed by a slight decline to 70 weeks. There were very small differences in ammonium changes during incubation due to storage period in G3 and B3. In R2 ammonium levels during incubation increased moderately from nil to 16 weeks of storage, was little further affected to 52 weeks, but was further increased slightly to 72 weeks. In G3 and B3 soils changes in nitrate levels during incubation due to storage closely paralleled those of mineral N. In the R2 soil there was a fair decrease in nitrate due to incubation due to storage from nil to 16 weeks, followed by a fair increase to 32 weeks of storage and a moderate decrease to 70 weeks.

TABLE 21

Chap. 10 Expt. 20

EFFECT OF PERIOD OF AIR DRY STORAGE ON (i) MINERAL NITROGEN AND (ii) MINERALIZABLE NITROGEN CHANGES, AND (iii) CARBON DIOXIDE RELEASE DURING SUBSEQUENT INCUBATION FOR 3 WEEKS OF G3, B3 AND R2 SOILS

(i) MINERAL NITROGEN

(Results are in ppm on dry soil basis)

Initial values

Soil	NH_4-N	NO_3-N	min-N	pH
G3	2.1	21.7	23.8	8.0
B3	1.7	20.7	22.4	7.8
R2	14.3	16.8	31.1	4.7

	L E V E L S				ACCUMULATION		
	After 16 weeks storage						
Soil	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
G3	2.6	21.8	24.4	7.7	0.5	0.1	0.6
B3	2.2	20.5	22.7	7.5	0.5	-0.2	0.3
R2	14.8	16.7	31.5	4.6	0.5	-0.1	0.4
	After 32 weeks storage						
G3	3.9	21.3	25.2	7.8	1.8	-0.4	1.4
B3	2.5	21.1	23.6	7.6	0.8	0.4	1.2
R2	16.3	16.8	33.1	4.7	2.0	0	2.0
	After 52 weeks storage						
G3	1.6	22.3	23.9	7.7	-0.5	0.6	0.1
B3	0.7	22.4	23.1	7.6	-1.0	1.7	0.7
R2	13.5	16.8	30.3	4.7	-0.8	0	-0.8
	After 70 weeks storage						
G3	0.9	23.2	24.1	7.5	-1.2	1.5	0.3
B3	0.1	22.8	22.9	7.5	-1.6	2.1	0.5
R2	12.3	18.2	30.5	4.7	-2.0	1.4	-0.6

L.S.D ($P < 0.05$) NH_4-N 1.0, NO_3-N 1.4, min-N 1.4.

TABLE 21 (continued)

(ii) MINERALIZABLE NITROGEN

Initial values

Soil	NH_4-N	NO_3-N	min-N	pH
G3	1.0	27.1	28.1	8.2
B3	0.9	25.5	26.4	8.2
R2	9.7	25.4	35.1	4.6

	L E V E L S				ACCUMULATION		
	After 16 weeks storage						
Soil	NH_4-N	NO_3-N	min-N	pH	NH_4-N	NO_3-N	min-N
G3	1.1	29.9	31.0	7.8	0.1	2.8	2.9
B3	1.0	27.4	28.4	7.9	0.1	1.9	2.0
R2	13.7	17.1	30.8	4.5	4.0	-8.3	-4.3
	After 32 weeks storage						
G3	1.7	30.5	32.2	7.9	0.7	3.4	4.1
B3	1.6	30.8	32.4	7.8	0.7	5.3	6.0
R2	13.3	24.4	37.7	4.7	3.6	-1.0	2.6
	After 52 weeks storage						
G3	0	29.7	29.7	8.0	-1.0	2.6	1.6
B3	0	26.3	26.3	8.0	-0.9	0.8	-0.1
R2	14.0	21.5	35.5	4.6	4.3	-3.9	0.4
	After 70 weeks storage						
G3	0	30.5	30.5	7.6	-1.0	3.4	2.4
B3	0	25.2	25.2	7.5	-0.9	-0.3	-1.2
R2	15.7	20.5	36.2	4.8	6.0	-4.9	1.1

L.S.D ($P < 0.05$) NH_4-N 1.1, NO_3-N 1.7, min-N 1.7

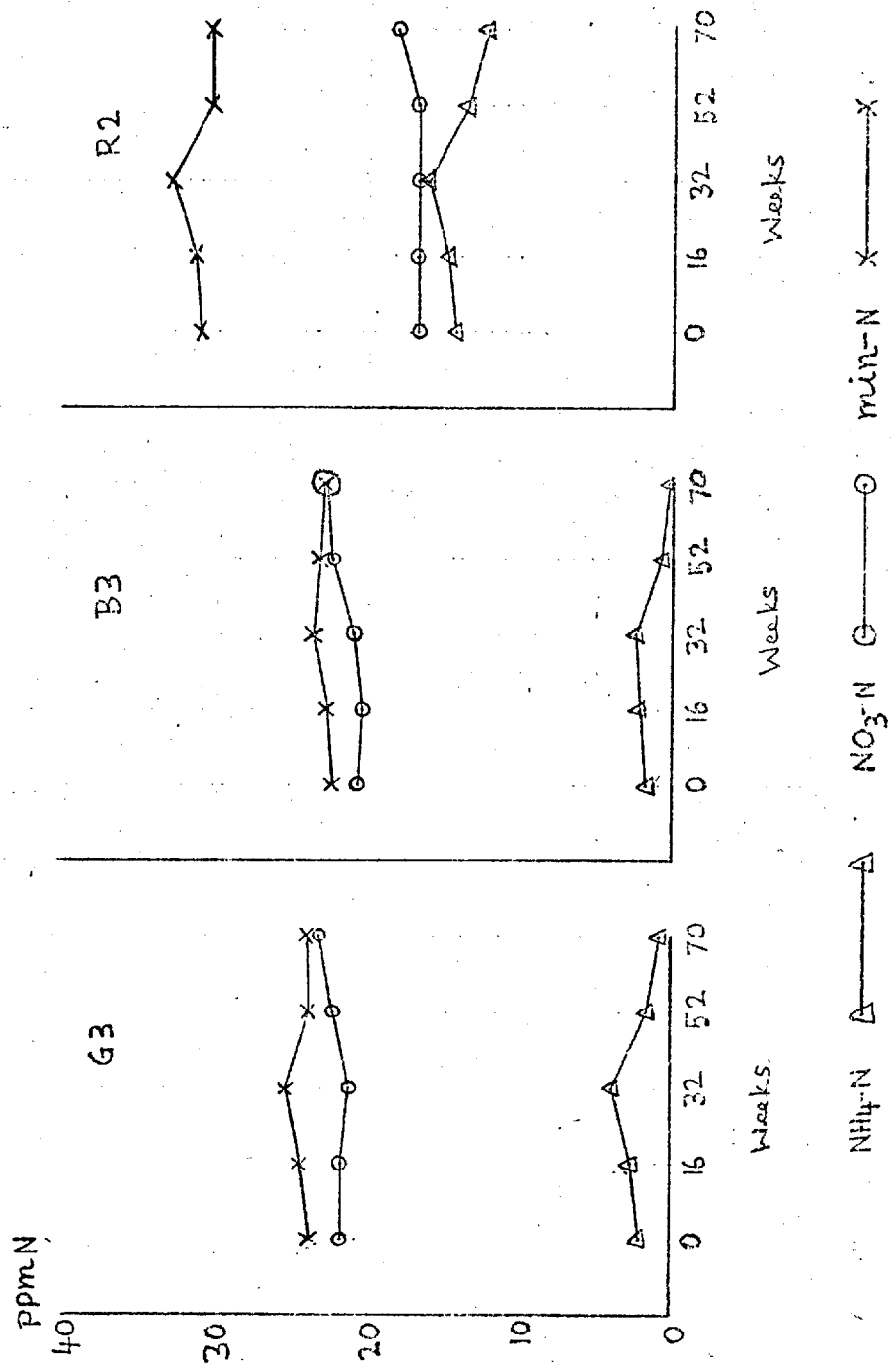
(iii) CARBON DIOXIDE RELEASE

Soil	0 wk.	16 wks.	32 wks.	52 wks.	70 wks
G3	755	955	970	1005	940
B3	730	955	705	665	745
R2	620	845	850	860	805

L.S.D ($P < 0.05$) 185

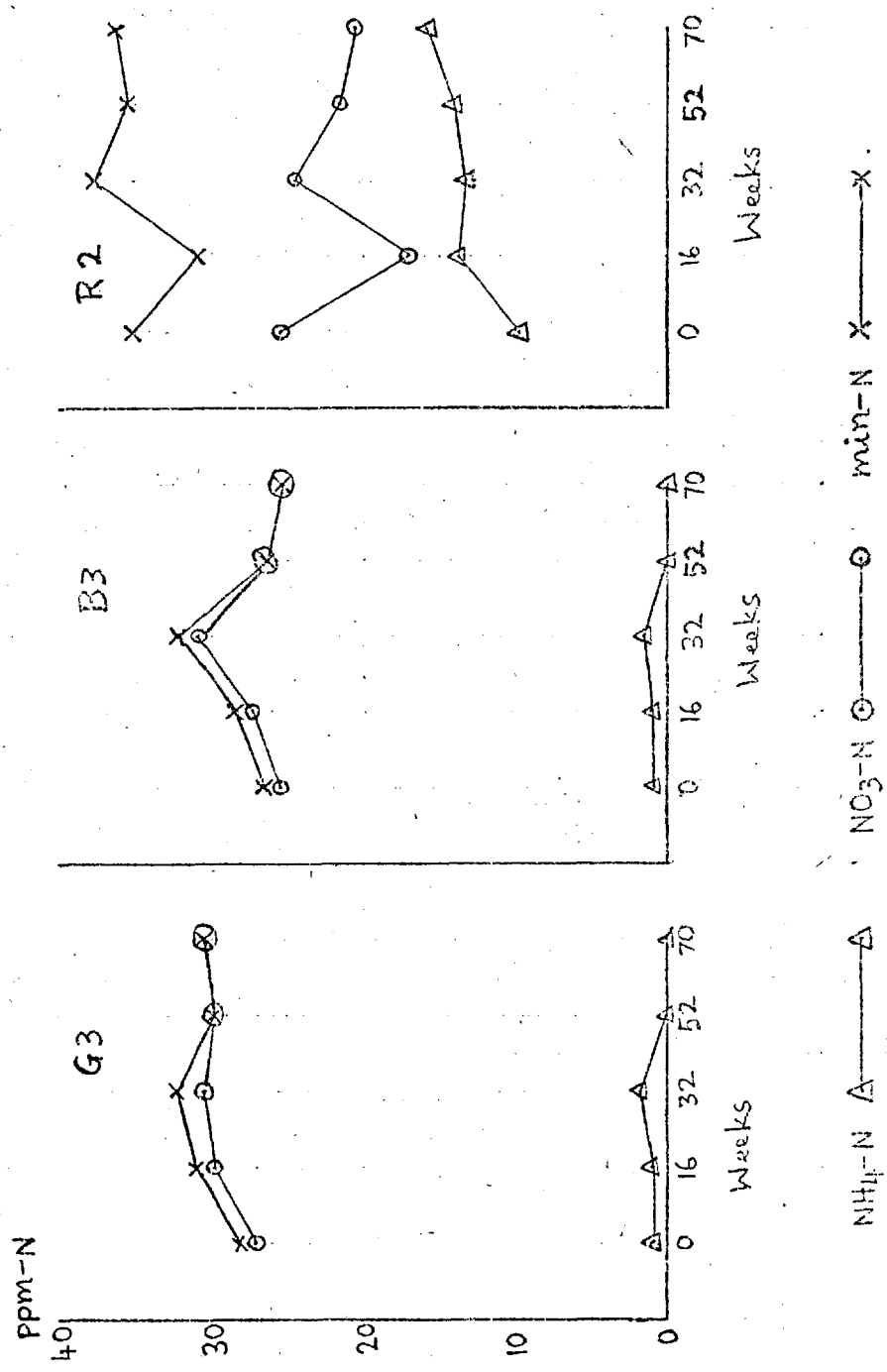
CHAPTER 10 Expt.20 Fig.18

Effects of period of air-dry storage on mineral N levels in G3, B3 and R2 soils.



CHAPTER 10 Expt.20 Fig.19

Effects of period of air-dry storage on mineralizable N during subsequent incubation for 3 weeks of G3, B3 and R2 soils.



The increases in mineralizable N in G3 and B3 soils with storage to 16 weeks were similar to results obtained by Birch (234) with African soils, but the magnitude of the increases were much less in the Bangladesh soils. In the R2 soil there was a definite decline in mineralizable N by 16 weeks storage. Air-drying of soils may induce temporary or partial sterilizing effects on ammonifying and nitrifying organisms. This could account for the decrease in nitrate accumulation during incubation after 16 weeks storage in R2, and suggests that air-drying had a temporary sterilizing effect on nitrifying organisms in the acid R2 soil. No such effect occurred, however, in the slightly alkaline G3 and B3 soils, which suggests that temporary sterilization is more active under acid than under slightly alkaline conditions.

In general the results obtained with all three soils from Bangladesh showed that they could be held air-dried for a long period (at least 70 weeks) and yet when subjected to moist incubation the activity of the N mineralizing and nitrifying organisms were usually little different after 70 weeks of air-dry storage than immediately after air drying. Where differences between this study and those reported by other workers occurred, these may have been due in part to differences in the methods of air drying (time, temperature, humidity) or in methods of storing the air-dry samples.

Carbon dioxide release (Carbon mineralization) was greater after 16 weeks than after no storage in all three soils. In the G3 and R2 soils there were no further significant changes in carbon mineralization with further storage to 70 weeks. In B3 carbon mineralization after 32 to 70 weeks of storage was similar to that obtained after no storage. There was no correlation between mineral N accumulation and carbon mineralization during incubation with

increasing period of storage in any of the soils.

SUMMARY

The effects of period of air-dry storage (0, 16, 32, 52 and 70 weeks) of G3, B3 and R2 soils on mineral N levels and mineralizable N (3 weeks incubation at 30° and 50% saturation) and carbon were studied. There were relatively small changes, though some of these were significant, in mineral N levels in all three soils with increasing legnth of air-dry storage. Mineral N and ammonium increased slightly to 32 weeks of storage and decreased slightly to 70 weeks in all three soils.

The G3 and B3 soils behaved similarly in that mineralizable N increased with storage to a maximum at 32 weeks, whilst in the R2 soil it decreased to 16 weeks but increased to 32 weeks. With further storage mineralizable N in all three soils decreased to 52 to 70 weeks of storage. In all three soils nitrate accumulation changes paralleled those of mineralizable N. Very little or no ammonium accumulated in the G3 and B3 soils, whilst in R1 there was a moderate accumulation of ammonium, with a trend for increase with period of storage.

Carbon dioxide release during incubation was greater after 16 weeks than after no storage in all three soils. Carbon dioxide release from G3 and R2 was not affected further by storage up to 70 weeks. In B3 it decreased to 32 to 70 weeks to levels similar to that after no storage.

CHAPTER 11

GENERAL SUMMARY

BIBLIOGRAPHY

CHAPTER 11

GENERAL SUMMARY

Samples of Gangetic alluvial soils (G soils, pH 7.6 to 8.0) Brahmaputra alluvial soils (B soils, pH 7.4 to 7.8) and Red soils (R soils, pH 5.1 to 5.2) from Bangladesh were studied with respect to changes in mineral N forms and (in some experiments) carbon dioxide release during incubation with various superimposed treatments. Most of the experiments were done with G1 (pH 7.6), B1 (pH 7.4) and R1 (pH 5.2) soils and the results are discussed mainly in relation to the differences in responses among the three soil types. Some characteristics of these soils and of the other G, B and R soils used are shown in Table 1.

The variables studied involved the effects of addition of different sources of N (ammonium sulphate, urea, dried blood, and hoof and horn) and organic materials (straw and grass). The effects of varying temperature and moisture content of incubation, alteration of pH by addition of sulphur and calcium carbonate, and addition of varying levels of sodium as chloride and sulphate were studied. Fixation of added ammonium and mineralization of fixed ammonium during incubation, loss of nitrate by denitrification during waterlogged incubation, and effects of period of air-dry storage on mineral N and mineralizable N (during incubation) were also studied.

When G1, B1 and R1 soils were incubated to 6 weeks without addition of any material (Chap.3, Expt.1), G1 and B1 accumulated more nitrate than did R1 to 3 weeks, but by 6 weeks nitrate accumulation was greater in B1 than in G1 and R1. Where 50 ppm N as ammonium sulphate was added about half the added ammonium was fixed initially by G1 and B1, but none was fixed by R1. Most of the nitrification of added ammonium in G1 occurred during the first 3 weeks, but in B1 and

R1 it occurred in the second 3-week period. Addition of ammonium sulphate had negligible effects on carbon dioxide release from all soils.

Where 100 ppm N was added as ammonium sulphate and urea to G1, B1 and R1 soils (Chap. 3, Expt.2) all the nitrification of added ammonium which occurred did so during the first 2 weeks in G1, but most of the nitrification in B1 occurred during the 2-6 week period. This suggests that the activity of nitrifying organisms in G1 was greater than that in B1 with respect to nitrification of added ammonium, or that the nitrifiers in B1 showed a lag phase, or that 100 ppm added ammonium was toxic initially to nitrification in B1. Most of the nitrification of urea which occurred in G1 and B1 did so during the first two weeks. There was no nitrification of added ammonium sulphate or urea in R1 even by 6 weeks. The inhibition of nitrification in R1 by ammonium addition suggests that heterotrophic nitrification was operative in the control soil.

Incubation of G2 soil (6% calcium carbonate) with 100 ppm N added as ammonium sulphate and urea (Chap.3, Expt.3) showed a small accumulation of nitrite by 2 weeks, but only with the ammonium sulphate treatment, and the nitrite had disappeared by 6 weeks. There was no loss of N as ammonia gas with either treatment. By 6 weeks nitrification was similar with both treatments.

The effects were studied (Chap.4, Expt.4) of incubating G1, B1 and R1 soils over 12 weeks after addition of 0.5% ground straw and grass and 100 ppm N as ammonium nitrate (to ensure that mineral N was not limiting the decomposition of the added organic materials). In all soils by 12 weeks of incubation straw caused more immobilization of N than did grass. Immobilization due to straw was twice as great in G1 and B1 soils than in R1 after 12 weeks. In G1 and B1

immobilization of mineral N due to decomposition of straw and grass was accounted for largely or entirely as nitrate. In R1 with straw immobilization of mineral N was accounted for entirely as ammonium after all incubation periods and there was net mineralization of nitrate, particularly after 12 weeks. In R1 with grass there was net immobilization of nitrate by 2 weeks, but net mineralization of nitrate by 12 weeks. The apparent recovery of carbon as carbon dioxide from the added organic materials was greater from grass than from straw, particularly in the R1 soil. Recovery of carbon dioxide from straw was about the same from G1 and B1, and much less from R1. With grass, carbon dioxide recovery from the added organic materials was only slightly lower from R1 than from G1 and B1.

The effects of adding varying levels of sulphur (0.1 to 1.0%) to G2 soil (6% calcium carbonate) on subsequent changes in mineral N during incubation to 13 weeks were studied (Chap.5, Expt.5). Where no ammonium sulphate was added nitrification and N mineralization decreased with increasing sulphur level and both processes were stopped by 0.5 and 1.0% sulphur. Where 100 ppm N as ammonium sulphate was added nitrification to 6 weeks decreased with increasing sulphur to 0.2% and was stopped by higher sulphur levels. By 6 weeks nitrification was greater with 0.1% than with 0.2% sulphur, but by 13 weeks nitrification was the same with both these sulphur levels. By 13 weeks there were net decreases in nitrate and, particularly, in ammonium with 0.5 and 1.0% sulphur.

In the B2 soil (0.3% calcium carbonate) treated with 0.1 and 0.2% sulphur (Chap.5, Expt.6), where no ammonium sulphate was added nitrification decreased with increasing sulphur level, whilst ammonium accumulated only with 0.2% sulphur. Where ammonium sulphate was added nitrification decreased considerably with increasing sulphur level.

With 0.2% sulphur there was slight loss of nitrate by 6 weeks but some accumulation by 13 weeks. Ammonium was not affected by 0.1%, but was increased by 0.2% sulphur.

In the R2 soil (pH 5.1) where no ammonium sulphate was added (Chap.5, Expt.7) nitrification was stopped by 0.1% sulphur but was increased considerably by both levels of calcium carbonate (0.3 and 0.6%). Where ammonium sulphate was added nitrification was stopped by 0.1% sulphur but there was moderate accumulation of ammonium. With both calcium carbonate levels there was considerable nitrate accumulation and considerable decreases in ammonium. Results are discussed in relation to the likely occurrence of heterotrophic nitrification in the R2 soil.

Mineral N changes and carbon dioxide release were studied during incubation to 12 weeks of G1, B1 and R1 soils treated with 100 ppm N as dried blood (DB) and hoof and horn (HH) (Chap.6, Expt.8). The apparent mineral N accumulation values from DB and HH were higher in R1 than in G1 and B1 by 3 weeks, but by 12 weeks it was similar in all three soils. Ammonium accumulation from DB and HH in R1 was greater than from G1 and B1 by 3 weeks, but there was no accumulation of nitrate from either added N source in any of the soils. By 12 weeks ammonium accumulation from DB and HH occurred only in R1. Nitrate accumulation from both sources to 12 weeks was greater in G1 and B1 than in R1. The decomposition of DB and HH, as measured by apparent carbon dioxide release from these materials, showed that both materials tended to decompose more rapidly early in incubation in B1 than in G1 and R1 and the differences increased with incubation time.

The effects were studied (Chap.7, Expts.9, 10, 11) of addition of 0.1% to 1.0% sodium chloride and compared with the same levels of sodium applied as sulphate to G1, B1 and R1 soils treated with ammonium

sulphate (100 ppm N) on mineral N changes and carbon dioxide release during incubation to 6 weeks. In G1 and B1 soils nitrification was little affected by 3 weeks by 0.1% NaCl, but decreased with increasing levels and was stopped by 1.0% sodium chloride. During 3-6 weeks there was further nitrate accumulation with 0.1, 0.25 and 0.5% sodium chloride. In R1 nitrification was stopped by all sodium chloride levels by 3 weeks, but by 6 weeks there was some nitrification, but only with 0.1% sodium chloride. Mineral N changes during incubation due to increasing sodium sulphate levels were generally smaller than those due to equivalent levels of sodium as chloride. Carbon dioxide release from all soils was affected much less by increasing levels of both added salts than were mineral N levels. Carbon dioxide release declined in the order G1, B1, R1. Decreases in carbon dioxide release were similar with all levels of sodium chloride in R1 but in G1 only 1.0% NaCl decreased CO_2 release. In B1 it was decreased to the greatest extent by 0.1% NaCl. In G1 and R1 only the 1% sodium sulphate level increased carbon dioxide release. In B1 only 0.5 and 1.0%, whilst in R1 only 0.25 and 0.5% sodium sulphate, decreased carbon dioxide release.

The effects of moisture level(25,50,75,100 and 133% saturation) during incubation to 6 weeks of G1, B1 and R1 soils on mineral N changes and carbon dioxide release without and with addition of 100 ppm N as ammonium nitrate were studied (Chap.8, Expts. 12, 13. 14). Where no N was added nitrification in G1 and B1 increased with moisture content to 50 or 75% saturation, but decreased to low levels or nil at 100% and 133% saturation (waterlogged). In R1 nitrification by 3 weeks increased with moisture to 50% saturation, but was stopped at the higher moisture contents. By 6 weeks nitrification in R1 was at a maximum at 75 and 100% saturation, but was stopped at 133%.

Where ammonium nitrate was added maximum nitrification occurred at 50% saturation in G1 and B1 and at 75% saturation in R1. There was considerable loss of nitrate, presumably by denitrification, at 100 and 133% saturation in all three soils. Where ammonium nitrate was added mineral N accumulation in G1 and B1 was considerably lower than that of nitrate or there was more loss of mineral N compared with nitrate at each moisture level. In R1 where no ammonium nitrate was added mineral N accumulation increased with moisture level to a maximum at 133% saturation by 3 and 6 weeks, whilst where N was added maximum mineralized N occurred at 25 to 75% saturation. Mineralized N was accounted for almost entirely as ammonium by 3 weeks, whilst by 6 weeks it was accounted for as nitrate at 50 and 75% saturation where N was added but as ammonium at 25% saturation. At 133% saturation where ammonium nitrate was added there was complete loss of added nitrate by 3 weeks from all three soils. At 100% saturation by 6 weeks all added nitrate was lost from B1, about 60% from R1 and about 20% from G1. Loss of carbon dioxide from G1 was lower at 25 and 133% saturation than at intermediate moisture contents, whilst from B1 it was lower at 25% saturation than at the higher moisture contents. In R1 without added N carbon dioxide release was at a maximum at 75% saturation, whilst with added N it increased with moisture content to maxima at 100 and 133% saturation.

The effects of varying temperatures (20^{o} to 60^{o}) on mineral N changes and carbon dioxide release were determined during incubation (50% saturation) to 6 weeks of G1, B1 and R1 soils alone and treated with 100 ppm N as ammonium sulphate (Chap.9, Expts.15, 16, 17). Where no N was added nitrification and N mineralization in G1 and B1 increased with temperature up to 40^{o}. At 50 and 60^{o} nitrification was very low, whilst N mineralization decreased somewhat. In R1

nitrification was at a maximum at 30°, but decreased with increasing temperature to nil at 40 and 60°. In G1 and B1 N mineralization was accounted for entirely as nitrate up to 40°, but almost entirely as ammonium at 50 and 60°. In R1 N mineralization increased with temperature up to 60°. N mineralization in R1 was accounted for largely as nitrate at 30°, as both ammonium and nitrate at 20 and 40° and entirely as ammonium at 50 and 60°.

Where N was added nitrification increased to the greatest extent in G1 and B1 at 30°, but was absent at 50 and 60°. There was moderate N mineralization, but only at 30°, in G1 and B1. In R1 N mineralization increased with temperature up to 40°, but was little further affected at 50 and 60°. There was some nitrification in R1, but only at 30°.

In G1 and B1 soils carbon dioxide release increased with temperature to a maximum at 60°, the rate of increase being greater in G1 than in B1. Addition of N in general had little effect on carbon dioxide release at any temperature. In R1 where no N was added carbon dioxide release increased slightly with temperature to 30-40°, decreased slightly at 50° and increased slightly again at 60°. Where N was added carbon dioxide release increased moderately with temperature to 30°, but declined with further increasing temperature to 60°, to about the same level at 20°.

The clay fractions of G3, B3 and R2 soils were separated and after destruction of organic matter the clays were saturated with ammonium and fixation was induced by drying at 100° for 24 hours (Chap.10, Expt. 18). The extent of fixation of ammonium was 426, 252 and 44 ppm N for G3, B3 and R2 clays respectively. When the clays were mixed with sand and appropriate soil inoculum and incubated (30° and 50% saturation for 6 weeks) 77, 100 and 89% of the fixed ammonium was mineralized in G3, B3 and R2 clays respectively.

Mineralized N accumulated entirely as nitrate in G3 and B3 clays but entirely as ammonium in R2.

The extent of loss of nitrate by denitrification during waterlogged incubation (6 weeks at 30°) of G1, B1 and R1 soils treated with 2% straw and 500 ppm N as potassium nitrate was studied (Chap.10, Expt.19). By 3 weeks 78.0, 79.2 and 23.4%, whilst by 6 weeks 85.4, 84.0 and 90.2% of the added nitrate was lost from G1, B1 and R1 soils respectively.

Changes in mineral N levels due to period of air dry storage (0 to 70 weeks) of G3, B3 and R2 soils were relatively small, though sometimes significant (Chap.10, Expt.20). Mineral N and ammonium increased slightly to 32 weeks of storage and decreased slightly to 70 weeks in all soils. Mineralizable N (after 3 weeks incubation at 30° and 50% saturation) in G3 and B3 increased with period of air-dry storage to a maximum at 32 weeks, whilst in R2 it decreased to 16 weeks but increased to 32 weeks. With further storage mineralizable N in all three soils decreased to 50-72 weeks. Changes in nitrate paralleled those of mineralizable N. Negligible ammonium accumulated in G3 and B3, whilst in R2 there was moderate ammonium accumulation, tending to increase with period of air-dry storage. Carbon dioxide release during incubation was greater after 16 weeks than after no storage in all three soils. Release from G3 and R2 was not further affected by storage up to 70 weeks. In B3 it decreased to 32-70 weeks to levels similar to that after no storage.

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