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SOIL NITROGEN STUDIES WITH PARTICULAR REFERENCE
TO FRUIT-TREE NUTRITION

I. SEASONAL VARIATIONS in the MINERAL NITROGEN STATUS and
in pH of an ORCHARD SOIL under CLEAN-CULTIVATION and
PERMANENT SOD

II. The COMPARATIVE BEHAVIOUR OF NITRATE and AMMONIA added
in NITROGENOUS FERTILIZERS to a SILT-LOAM SOIL

by

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Being a thesis submitted in partial fulfilment of the
requirements for the degree of M.Agr.Sc.(Hort.) of the
University of New Zealand.

Massey Agricultural College.

December 1952.

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PART ONE

CHAPTER I

INTRODUCTION

The importance of nitrogen for the nutrition of fruit trees is well established and it is largely for this reason that much attention has been given by overseas workers to factors influencing the level of soil mineral nitrogen. Soil management methods have been shown to exert a considerable influence on mineral nitrogen level of the soil, those methods which make nitrogen available most readily depleting the total supply in the soil most rapidly.

In view of the importance attached by overseas workers to the influence of soil management practices on the level of the soil mineral nitrogen, and as no previous study of this problem appeared to have been made in New Zealand, the present investigation was undertaken. A study was made to compare the effects of clean-cultivation and sod-culture on both the mineral nitrogen level and pH in a silt-loam orchard soil over a period of several months. This afforded an opportunity to investigate also the effect of seasonal factors on the periodic variations in mineral nitrogen under both systems of management.

CHAPTER II

REVIEW OF LITERATURE

AMMONIA AND NITRATE IN CULTIVATED AND GRASSLAND SOILS

Fluctuations in the ammonia and nitrate contents of fallow and grassland soils have been reported by a number of workers, in England (Russell, 1909, 1914; Eggleton, 1934, 1935; Richardson, 1935, 1938 and others), South Australia (Prescott and Piper, 1930), South Africa (Hall, 1921) and elsewhere. It is not intended here to comment on every paper that is available but rather to review a selection of those published that cover, from similar aspects, the points of the present investigation.

One of the first contributions to the study of ammonia fluctuations in arable soils appears to have been that of Russell in 1909. He found that from spring to autumn, ammonia tended to be at a constant minimum, the level depending on the quantity of organic matter present. Ordinary arable soils contained one or two parts per million (p.p.m.) while rich dunged and garden soils contained three or four parts per million in the top nine inches. This constant low ammonia status is to be expected in soil conditions where nitrification is proceeding at a greater rate than ammonia production.

A more critical study of nitrate fluctuations of arable soils was made later by Russell (1914). He showed nitrate to be at a maximum in late spring or early summer

in fallow arable land at Rothamsted. There was a very rapid rise from the winter minimum to the early summer maximum in May or June, but the onset of the rise was delayed after mild wet winters and was more rapid after a drier and colder winter. Russell also showed that a hot dry summer favoured accumulation of nitrates in loams and a cold wet summer did not, a fact which has generally been supported by other workers under similar climatic conditions.

Russell showed that nitrate fluctuations were greatest in loams and least in clay soils; loams being more suitable for the accumulation of nitrates, with clays next and sand least suitable, but sands and loams lost their nitrates more completely in winter than clays. Russell also showed that nitrate did not generally accumulate beyond certain limits, which he found were, sand 6 p.p.m., loam 23 p.p.m. and clay 14 p.p.m. for the top eighteen inches. He stated however, that heavily dunged loams sometimes contained up to 37 p.p.m. of nitrate nitrogen. No explanation was given for this apparent limit to nitrate accumulation which has not been indicated by other workers. Nitrate production is known to be limited by such factors as soil temperature, moisture, aeration, the presence of ammonia, the absence of toxic or inhibiting substances and other factors. Unfortunately Russell did not investigate ammonia fluctuations along with nitrate fluctuations, although he indicated in the earlier paper (1909) that ammonia tended to be at a minimum of up to four parts per million in the

top nine inches.

Russell and Appleyard (1917) in investigating the decomposition of organic matter in soil, found a close resemblance between the curves for bacterial numbers, carbon dioxide, (except for a period on cropped land) and nitrate, sufficient for them to conclude that they were all related. The curve for nitrate, however, had a two to three weeks' lag behind that for bacterial numbers. This, they suggested pointed to two stages in nitrate production, one related to bacterial numbers and the other not. They refuted the view that the two stages were simply ammonia production and nitrate production, but suggested that ammonia production itself occurred in two stages. Unfortunately no attempt was made to study nitrifying bacteria separately from total bacteria.

Following work on the Rothamsted Park Grass plots Richardson (1933) stated:

"In grassland soils there is found to be a close-knit equilibrium in which under normal conditions neither ammonia nor nitrate accumulates to any considerable extent, although the ammonia level is consistently higher than the nitrate level."

This he ascribed in part to poor conditions in the field for nitrification and also to the greater mobility and thus the more rapid availability of the nitrate than the ammonia in the soil. Richardson (1935, 1938) later confirmed this view, finding equilibrium levels for nitrate

and ammonia in grassland soils subject only to minor fluctuations. These fluctuations could not be systematically related to changes in climatic factors or to the growth of the crop, and in any case were small compared with those in the nitrate content of arable soils.

Eggleton (1935), however, found in a newly sown grassland in England a definite accumulation of nitrate during February, an unusually dry month, though rainfall in March accompanied by active grass growth caused a loss of the nitrate. He concluded that nitrification took place at a temperature too low for the growth of the grass.

Eggleton (1934) found ammonia comparatively high (up to 18 p.p.m. in August) and nitrate low (maximum of 10 p.p.m. in early spring) throughout the growing season in 4-inch samplings under grassland, and attributed this to the poorer conditions for nitrate accumulation normally existing under grassland which he stated to be due firstly to uptake of nitrate by the herbage, secondly to the greater numbers of micro-organisms and therefore greater nitrogen demand and thirdly ^{to} some effect of the grass plant in depressing nitrification. From the results of daily samplings for ten days in early summer he supposed there to be an inverse relationship between ammonium-nitrogen and nitrate-nitrogen. There seems to be no justification for expecting this relationship, but rather to expect there to be a lag between the peaks for ammonia production and those for nitrate pro-

duction, if one could eliminate outside interference such as increased uptake of inorganic nitrogen by plant roots. Eggleton's interpretation of an inverse relationship could be equally well interpreted as an approximate one to two day lag between ammonia production and nitrate production.

Richardson (1938) also found that in limed grass plots the ammonia content was consistently higher by up to two parts per million than in the unlimed plots. This he explained by suggesting that liming, by encouraging microbial and especially bacterial activity, caused a greater "ammonia pressure", and so a rise in the ammonia equilibrium level on the limed plots.

INFLUENCE OF DEPTH

In general, ammonia and nitrate production have been found to decrease with depth, as conditions for bacterial activity are generally not so suitable in the lower layers of a soil as in the upper layers.

Prescott and Piper (1930) in South Australia studied the distribution of nitrate with depth under fallow soil in autumn and found the greater amount to be located in the surface mulch as follows:

Depth in inches	NO ₃ (p.p.m.)
0 - 3½	72
3½ - 9	7
9 - 18	6

The first of the autumn rains washed down the nitrate from the surface soil and redistributed it in the top 18 inches.

Later rains and the growing crop prevented any further accumulation in the surface layer.

For grassland soils, Richardson (1938) found in two comparable Park Grass plots that total mineral nitrogen decreased in concentration with depth in successive 5 cm. layers down to 20 cm. as follows:

Depth in cm.	Total mineral N (p.p.m.)	
	Soil A	Soil B
0 - 5	9.8	10.0
5 -10	5.4	8.9
10 -15	5.3	8.0
15 -20	4.4	5.6

He suggested, however, that to a considerable extent the increase in soil density offset this difference in mineral nitrogen, so that each 5 cm. layer made an almost equal contribution to the total amount present to a depth of 20 cm.

Hall (1921) in South Africa investigated the nitrifying power of one soil at different depths in April, by incubation, and found little ability to produce nitrate below two feet. No explanation was given for this result although Hall did state that the lower depths had much less organic matter than in the first two feet.

Krantz et al. (1943) in U.S.A. found that during seasons of prolonged droughts, nitrates moved upwards in the soil to accumulate at the surface, a movement apparently correlated with the upward movement of soil moisture at that time.

Subsoil storage of nitrates depends largely on climate and on rainfall in particular, and also on soil type.

Russell (1950) reasoned thus:

"The reason that heavy soils can hold nitrates in their subsoil against drainage during winter is presumably because the drainage water can only move through cracks and channels in the soil whilst the nitrates can be held inside the principal structural units in the subsoil, through which the drainage water cannot move."

CHANGES IN pH

Very little work appears to have been carried out on pH fluctuations in relation to changes in nitrate and ammonia.

In discussing grassland soils, Eggleton (1934) dismissed the point briefly thus:

"In common with all the other soil factors recorded in this experiment, the pH fluctuated markedly from week to week, but certain trends were apparent. The soil on the control plots became progressively more acid as the season advanced, reaching a point of maximum acidity in September. Thereafter the reaction tended to become less acid, until at the end of the season it approximated to its spring value. This development of acidity is doubtless connected with the accumulation of solutes in the top layers of the soil under the influence of transpiration and evaporation."

No simple relationship to nitrate accumulation was indicated by Eggleton, and unfortunately the soil pH values were not shown.

Lehr (1950) in investigating the influence of nitrification on seasonal fluctuations in soil pH found no regular correlation between soil nitrate values and pH for the cropped soil, which he attributed to the influence of plants, though he found an approximately linear relation on the uncropped soil. He concluded that the pH variations were caused only partly by nitrification and attributed the seasonal pH changes to the neutral-salt effect in the soil.

In assuming that high soil ammonia caused a decrease in acidity, Thomson and Coup (1943-44) found that soil reaction fluctuated very much as expected. When ammonia was high, the pH figures were high and when nitrate was high and ammonia low, the pH was low. This assumption that soil pH varies with ammonia values as well as inversely with nitrate values can only hold in the absence of sufficient rainfall to leach the displaced bases out of the sampled horizons. Ammonia produced by ammonification of organic compounds will tend to displace absorbed bases, which, in wet periods will be leached and thus there will be no accumulation of bases and no consequent permanent increase in soil pH.

In a recent paper, Doak (1952) in New Zealand showed that the pH of the soil of a urine patch rose from 5.5 to a maximum of 9.2, then after remaining constant for several days very gradually fell to about 7.8 after which the rate of fall

increased very greatly due to rapid nitrification until the initial pH level was again reached. Thus nitrification caused a decrease in soil pH but this appears to have been due to the disappearance of ammonia rather than to the accumulation of nitrate.

Swanbeck and Morgan (1930) correlated the nitrate content of the drainage water and the pH value of the soil in lysimeter experiments with weekly samplings. There was almost complete similarity between the pH- and nitrate-curves, though the fluctuations in the nitrate curve lagged somewhat behind those of the pH curve. They did not attempt to explain this lag in nitrate accumulation, but it suggests that in this case variations in soil pH were the cause rather than the result of fluctuations in the nitrate status.

EFFECT OF A GROWING CROP ON NITRATE ACCUMULATION

In 1914, Russell observed a depression in nitrate production in land cropped with non-leguminous plants when compared with comparable fallow land even after allowing for the nitrate absorbed by the crop. He postulated two different types of factors which might have accounted for this, negative factors such as lack of moisture or lower temperature on the cropped land, or some positive factor such as a possible direct effect of the growing plant on the nitrate (other than absorption) or on the decomposition processes going on in the soil. Russell concluded that less nitrate accumulated and apparently less was produced on cropped land than on

fallow land, even after allowing for that removed by the crop.

Russell (1950) later suggested that possibly the microbial population around the plant roots could have produced this effect if they could extract from the root system, or if the roots could excrete, an appreciable amount of carbohydrates. This implies that the entire process of nitrification takes place under plants as usual, the same amount of nitrate being produced as in the fallow soil, but owing to the root excretions, the nitrate is again consumed so rapidly by the nitrate consuming organisms developed under the stimulus of carbohydrate excretions, that none appears in the soil solution once the soil is fully occupied by roots. This theory therefore assumes that ammonia is depressed as well as nitrate in cropped soil.

This explanation of Russell and others is discounted by Theron (1951) for the following reasons.

1. The consumption by the microbial population around the plant roots of the nitrate formed normally would require the excretion of quantities of carbonaceous material far in excess of what the plant seems likely to part with.
2. Nitrate reappears immediately on the maturity and death of the crop, when the available supply of carbonaceous matter is high.
3. No nitrate accumulates under a dormant crop in winter, although nitrates were produced in bare soil.
4. If carbonaceous material were added to the soil,

ammonia as well as nitrates would be reassimilated by micro-organisms. However, under a crop ammonia is often present in quantities larger than is normally found in cultivated soils (Richardson, 1938).

Theron attributed the depression of nitrate accumulation to the direct influence of the living root, paralysing the autotropic dehydrogenase system of the nitrifying organisms without interfering with the process of ammonification. It is only after the plants are well established that the depressive influence is exerted effectively; with perennial grasses it is not apparent until the second season, after which it is maintained uninterruptedly.

"It is readily conceivable that the micro-organisms in the soil will be greatly favoured in the competition with the plants for the available supply of nitrogen if the process of mineralisation is interrupted at the ammonia stage, much more so than if the ammonia were oxidised to the very soluble and mobile nitrate radicle. Hence, although ammonification proceeds normally and uninterruptedly under a perennial cover, the supply of nitrogen to the plants will be restricted i.e. relative to what would be available if nitrification took place normally; the growth of such a vegetation would thus be curbed. The "root-bound" state of relatively low productivity, which makes its appearance soon after a perennial grass is properly established is thus readily intelligible,

as well as the marked response of the sward to applications of nitrogen, even in soils which under annual cropping would show no response whatsoever to nitrogenous fertilizers.

This state of affairs will naturally apply not only to perennial grasses but to any perennial cover which maintains living roots in the soil permanently, and a nitrogen deficiency must normally be expected to occur under such a cover irrespective of the soil - soils under legumes obviously excepted. This is confirmed, for example, by local (Pretoria) orchard practice in which it is found that citrus trees and fruit trees generally are, as a rule, greatly benefited by applications of nitrogenous fertilizers, whereas the response to phosphates is surprisingly slight." (Theron, 1951).

It must be remembered that Theron's statement is applied to non-leguminous plants, though presumably in the absence of effective strains of nodule bacteria, legumes too would show this effect. This point does not appear to have been investigated experimentally.

A depression of nitrification is also reported by Warrington (1905), Leather (1912), Prescott and Piper (1930), Goring and Clark (1948) and Theron (1948) for such widely varying conditions of soil and climate that this effect cannot be ascribed to incidental variations of moisture,

temperature or other environmental factors. Theron (1951) states that it is plainly due to a property common to all plants, particularly grass, the plant being able to establish a relationship in the biotic complex resulting in a depression of mineralisation of nitrogen contained in the organic matter of the soil.

CHAPTER III

EXPERIMENTAL MATERIAL AND METHODS

PLAN OF THE EXPERIMENT

Experimental plots were laid out in December 1951 in a grass orchard area on the Manawatu silt-loam soil series. The sward was composed principally of a vigorous perennial ryegrass/white clover mixture containing patches of cocksfoot (*Dactylis glomerata*) and red clover (*Trifolium pratense*). The area was planted with young standard apple and pear trees at a 24-foot square planting distance, and these were selected to define the positions of the blocks.

In 1946 the area was used as a vegetable garden but was abandoned early in 1948 owing to heavy infestation with *Oxalis* spp., and was converted to pasture by ceasing cultivation and sowing white clover. The trees were planted in 1948 and had been manured individually in the spring of 1950 with a 2:1 mixture of superphosphate and sulphate of ammonia at about one pound per tree. (Hockey 1952).

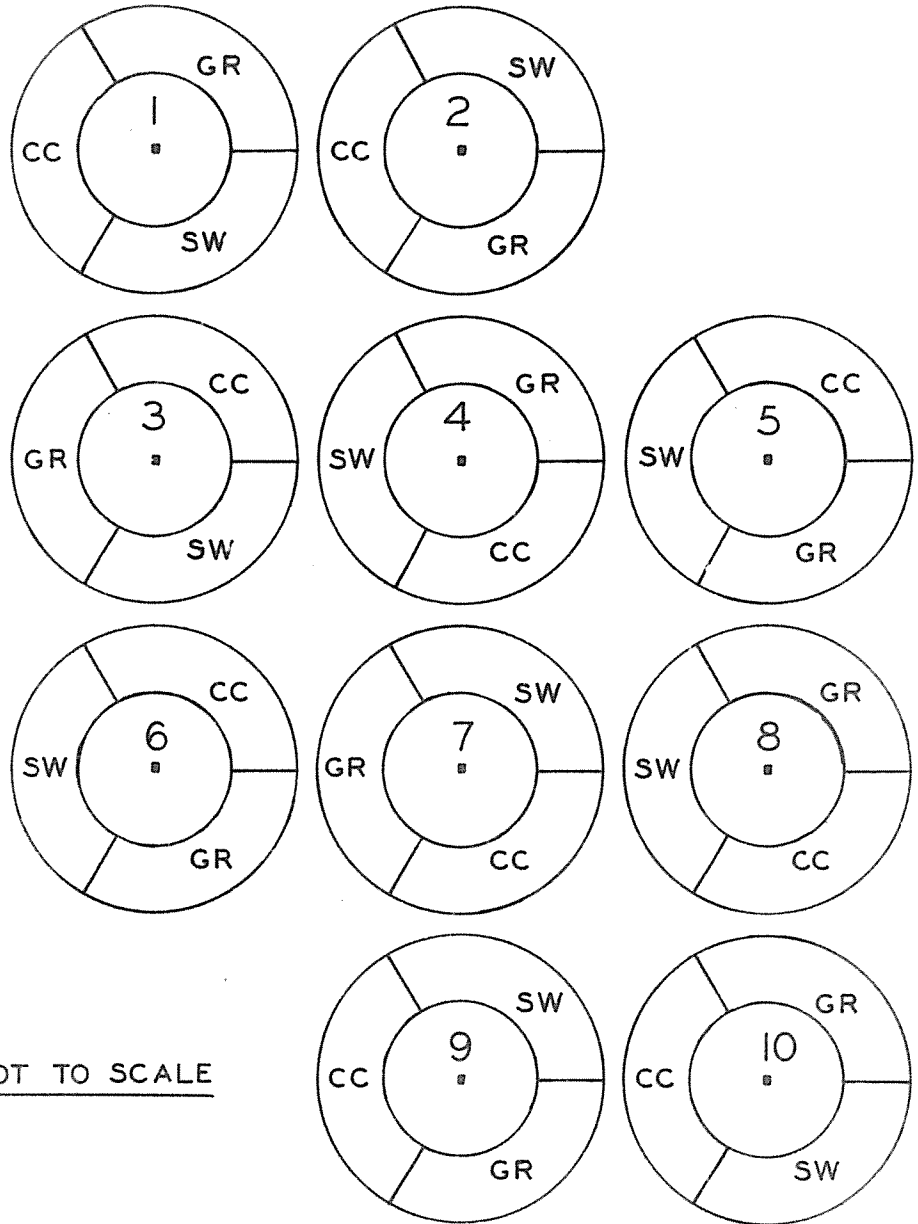
A total of ten experimental blocks, numbered 1 to 10 was laid down, each block comprising three plots, one for each of three soil treatments. Each block took the shape of a circular strip from 6 feet to 11 feet radius, with a tree as the centre point. The strip was divided evenly into three segments to form the component three plots. It was considered that the influence of the trees by shading and by root action would be negligible, as the "heads" of the

trees were not dense, and no tree roots were found beyond the 6 foot radius. However, to guard against the possibility of there being any active tree roots within the boundaries of the plots, a spade cut to a depth of about 18 inches was made around the inner edge of the blocks, at the 6 foot radius. A plan of the layout of the experimental area is shown in Figure I. All plots were completely randomized within the respective blocks.

"Student" (1937) has argued the case for the use of a planned plot technique for the minimising of error. That the use of such methods will minimise the error is not contested, but the essential point is concerned with the analysis of the results.

The analysis of variance methods used involves the estimation of error and this can only validly be done on the assumption that the plots are randomised. The estimation of error by these methods when planned plots are used is not statistically valid, although the actual method of analysis may be exactly the same.

"Student's" plea for the use of planned plots involves the development of new methods of analysis and work is being done on this problem, but it is outside the scope of this discussion. Randomised plots should therefore be used until appropriate methods of analysis are available for planned plots with their smaller actual components of error. Unfortunately "Student" died before his paper was completed and it is not known whether he may possibly have evolved a



NOT TO SCALE

Fig. 1. Plan of layout of the experiment. The symbols used are interpreted as follows: CC = clean cultivation, SW = sawdust mulch and GR = grassland.

suitable method of analysis for planned plot designs.

The respective plots were laid out and maintained as follows:

Treatment A. Clean Cultivation

On December 10th the grass was scythed, and on 13th and 14th an initial cultivation was carried out with a Howard "Bantam" rotary hoe. The plots were again cultivated on December 20th and 21st to a depth of about $1\frac{1}{2}$ inches, as, owing to persistent rain at that time, the chopped up turf had started regrowth. A further cultivation was carried out on January 11th and a final preparatory cultivation on January 23rd. At that date the soil worked down to a fine tilth and there were no obvious undecomposed grass residues remaining.

Regular shallow hand hoeing was thereafter carried out to check weeds such as seedling docks (*Rumex obtusifolius*) and fathen (*Chenopodium album*) and Oxalis which was particularly troublesome. On April 11th the edges of the plots were chipped back as white clover runners were severely encroaching on the cultivated areas. Directly after each sampling, all plots were hand-hoed to loosen foot marks and to fill in where soil cores had been removed.

Treatment B. Sawdust Mulch.

Preparatory cultivation was the same as that for the clean-cultivated plots, and on January 28th undecomposed pine sawdust was applied evenly to a 2-inch depth. However, owing to the persistent growth of Oxalis and the disturbance

of the mulch by chickens on one occasion, this treatment was abandoned and will be omitted from further discussion in this thesis.

Treatment C. Permanent Grassland

The treatment given these plots was a regular and frequent scything, the grass being left to rot in situ, to stimulate the orchard practice of frequent close gang-mowing. The grass was cut initially on December 12th and thereafter at about regular 3-weekly intervals until the end of the experiment in June.

SAMPLING METHODS

Sampling was always carried out between 9 and 10 a.m. Each sample comprised eight 2-inch cores taken at random along the approximate 17 foot length of sector of each plot, using the sampler described by Fife (1944). Care was taken to avoid sampling from within one foot of the edge of the plots. In the three earlier samplings, 2, 12 and 8 composite samples respectively from the top two inches were collected for each treatment. On February 25th four composite samples from within each of three plots for each treatment were taken in order to determine statistically variations within and between plots. Thus the number of samples needed for a required detectable difference between treatments was calculated. Starting on March 28th samplings were confined to only four plots, numbers 3, 6, 7 and 8, taking cores from each of two successive 2-inch depths, thus giving 16 composite samples in all for analysis.

This number of samples was found most convenient to handle, taking two full days for the preparation, sampling and analysis of nitrogen and other determinations that were done. All samples were collected in screw-top glass jars and taken to the laboratory, as soon after sampling as possible, for analysis.

CHEMICAL ANALYSIS - AMMONIA AND NITRATE

Ammonia was determined by Richardson's modification of Olsen's Method (Piper, 1942). A weighed quantity of soil is shaken up with 2 Normal potassium chloride solution, 2 Normal hydrochloric acid and toluene, and the filtrate is distilled with fresh magnesia and the distillate collected in 0.04N H_2SO_4 . The excess of acid is titrated with approximately 0.04N sodium hydroxide using methyl red as indicator.

The amount of ammoniacal nitrogen present is given as mg. per kg. (parts per million) of dry soil.

Nitrate was determined from the residue remaining after the determination of ammonia. To the residue was added a small amount of finely powdered Devarda's alloy and the distillation was recommenced into a further quantity of 0.04N sulphuric acid. The excess of acid was again titrated with approximately 0.04N sodium hydroxide using methyl red as indicator.

The amount of nitrate nitrogen present is expressed as mg. per kg. (parts per million) of dry soil.

MOISTURE DETERMINATION

Moisture was determined by drying 50 grams of the sample for 16 to 24 hours in an electric oven at about 105°C. Moisture is expressed as the number of grams of moisture lost on drying per 100 grams of dry soil.

SOIL pH DETERMINATIONS

Starting on March 28th, pH determinations were made on fresh soil samples within a few hours of sampling, using a Cambridge pH meter and a glass electrode filled with saturated potassium chloride solution. Determinations were made on a 1:2½ soil:water suspension allowed to stand for at least a quarter of an hour.

SOIL TEMPERATURE RECORDS

At the time of sampling, soil temperature readings were made at a one-inch depth for the earlier, and at one-and three inch depths for the later dates for each plot sampled, using ordinary glass laboratory thermometers pushed into the ground to the appropriate depth.

Soil temperatures are expressed in Centigrade units.

RAINFALL RECORDS

Rainfall figures were taken from the Meteorological records of Grasslands Division, D.S.I.R., Palmerston North. Rainfall was recorded at 9 a.m. and entered for the previous day.

Rainfall figures are given in inches and points.

STATISTICAL ANALYSIS

All figures were subjected to an analysis of variance using Snedecor's "F" test, to determine significant ($p = .05$) and highly significant ($p = .01$) differences between treatments, depths and sampling dates. (Snedecor, 1940).

Where relevant simple linear regression analyses were made to determine the existence of significant and highly significant relationships between groups of data, (Fisher, 1948), the line given by the regression equation $y = a + bx$ was fitted to the data by the method of least squares.

Where there were more than two variates with mutual relationships, multiple regression analyses were made. (Fisher, 1948). The plane given by the regression equation of the type $y = a + b_1x_1 + b_2x_2$ was fitted to the data by the method of least squares. (Snedecor, 1940).

CHAPTER IV

EXPERIMENTAL RESULTS AND ANALYSIS

AMMONIA IN CULTIVATED AND GRASSLAND SOIL

The ammonia figures at both depths for each treatment are given in Table I and presented graphically in Figure II.

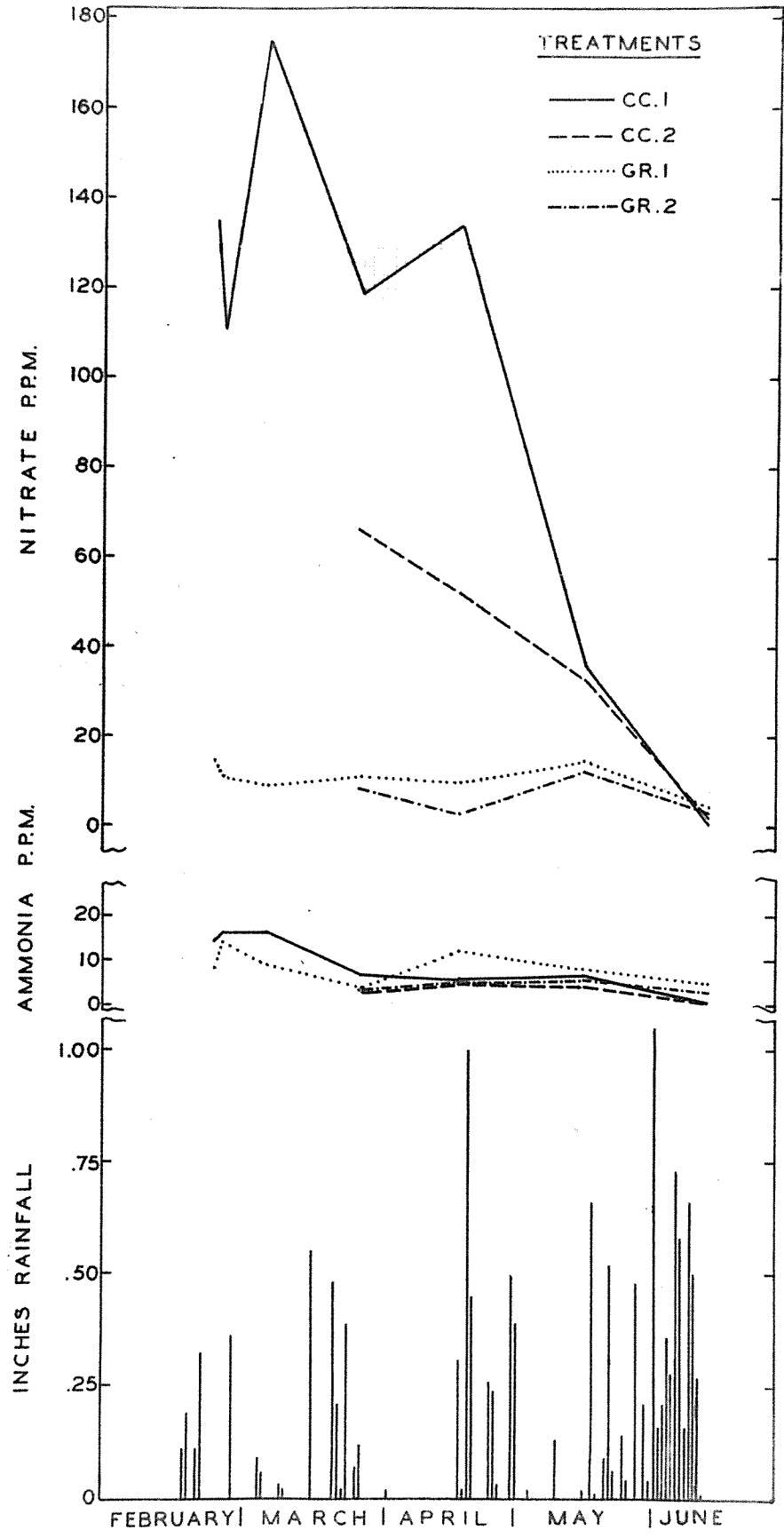
Table I

Mean Ammonium-Nitrogen p.p.m.

Date	Cultivated		Grassland	
	0" - 2"	2" - 4"	0" - 2"	2" - 4"
February 23	14	-	8	-
February 25	16	-	14	-
March 6	16	-	9	-
March 28	7	3	4	3
April 18	6	5	12.5	5.5
May 16	7	4.5	8.5	6
June 13	trace	trace	5	2

Ammonia in the surface horizon of the cultivated soil shows a gradual falling off in amount from 16 p.p.m. on both February 25th and March 6th, to a trace on June 13th, subject to minor fluctuations within that range of figures. That in the 2-to 4-inch depth of the cultivated soil shows a rise to a "peak" of 5 p.p.m. on April 18th after giving a figure of 3 p.p.m. on March 28th. In the surface of the grassland soil, the ammonia figures show an initial increase from 8 to 14 p.p.m. and then a decrease to 4 p.p.m. on March 28th, followed by a rise to 12.5 p.p.m. on April 18th, and then a gradual decrease to 5 p.p.m. on June 13th. In the lower depth

Fig. II The seasonal fluctuations in ammonium- and nitrate-nitrogen and the amount of rainfall received. The following symbols are used: CC.1 = clean cultivated at 0- to 2-inch depth, CC.2 = clean cultivated at 2- to 4-inch depth, GR.1 = grassland at 0- to 2-inch depth, and GR.2 = grassland at 2- to 4-inch depth.



of the grassland soil, the figures show a trend similar to that of the lower depth of cultivated soil, rising to 5.5 and 6 p.p.m. on April 18th and May 16th respectively and then falling off to 2 p.p.m. on June 13th.

The analyses of variance of the ammonia figures are summarised as follows, where the symbols used are N.S. = not significant at 5% level; S = significant at 5% but not at 1% level and H.S. = significant at 1% level.

Date	Between Treatments		Between Depths		Interaction		Error d.f.
	F	Result	F	Result	F	Result	
Feb. 23	-	-	-	-	-	-	-
Feb. 25	0.46	N.S.	-	-	-	-	21
Mar. 6	6.59	S	-	-	-	-	16
Mar. 28	4.24	N.S.	11.76	S	5.00	N.S.	9
Apr. 18	2.52	N.S.	5.20	S	3.48	N.S.	9
May 16	7.09	S	5.17	S	0.006	N.S.	9
June 13	13.47	H.S.	28.20	H.S.	4.29	N.S.	9

This shows that,

1. For separate dates, there were differences between treatments as follows:

March 6 and June 13, the ammonia status under clean-cultivation was greater than that under grassland.

May 16, ammonia under grassland was greater than that under clean-cultivation.

2. Comparing differences due to depth, on all dates on which observations were made, ammonia in the surface horizon was greater than that in the lower horizon.

3. There was no significant interaction between

treatments and depths - that is, the effect of depth on soil ammonia was not different for either treatment.

A relationship between soil temperature and the mean ammonia figures is shown by reference to Figure III. A regression analysis showed there to be a highly significant straight-line regression of the logarithm of the mean ammonia values, (in parts per million) on soil temperature. (Table II).

Table II

Regression of log. ammonia on temperature
Analysis of Variance "F" Test

Source	S.S.	d.f.	M.S.	F	5%	1%	Result
Due to regression	1.2977	1	1.2977	21.54	4.35	8.10	H.S.
Error	1.2048	20	0.0602				
Total	2.5025	21					

This means that there was a highly significant relationship, ammonia values being dependent on soil temperature, and increasing logarithmically with unit increase in soil temperature, as shown by the regression equation $y = .035x + .25$ where y is the dependent variable (log. ammonia) and x is the independent variable (soil temperature).

Likewise a negative straight line regression of the logarithm of the mean ammonia values on percentage soil moisture was found significant, as is shown in Table III.

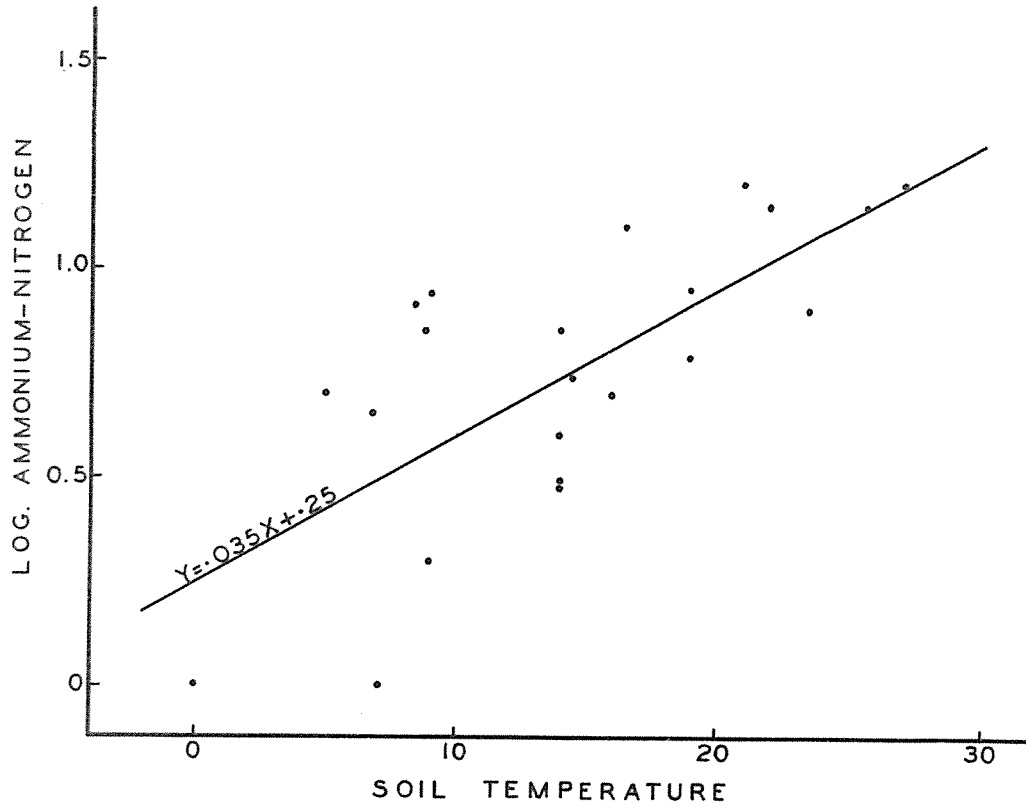


Fig. III. The relationship between soil temperature and soil ammonium-nitrogen.

Table III

Regression of log. ammonia on soil moisture
 Analysis of Variance "F" Test

Source	S.S.	d.f.	M.S.	F	5%	1%	Result
Due to regression	0.5380	1	0.5380	5.48	4.35	8.10	S
Error	1.9644	20	0.0982				
Total	2.5024	21					

The regression equation calculated by the method of least squares was $y = -.021x + 1.3$ which means that soil ammonia values decreased logarithmically with unit increase in percentage soil moisture.

However, a significant correlation (0.61) was also found between soil temperature and percentage soil moisture. It was therefore desirable to find if one or the other of the above relationships was due to this correlation.

A multiple regression analysis was carried out and the partial regression coefficients for temperature and moisture on ammonia values determined. These were +.01043 for soil temperature and + .009895 for soil moisture. The regression of ammonia on soil temperature independent of soil moisture was statistically significant while that of ammonia on moisture independent of soil temperature was not significant. This therefore shows that the ammonia value was dependent only on soil temperature and that the significant connection between moisture

and ammonia was spurious.

NITRATE IN CULTIVATED AND GRASSLAND SOIL

The figures obtained are presented in Table IV and shown graphically in Figure II.

Table IV

Mean Nitrate-Nitrogen p.p.m.

Date	Cultivated		Grassland	
	0" - 2"	2" - 4"	0" - 2"	2" - 4"
February 23	135	-	14	-
February 25	111	-	11	-
March 6	175	-	9	-
March 28	119	66	11	8
April 18	134	52.5	10	3
May 16	36	33	15	12.9
June 13	trace	1.7	4.6	2.6

The nitrate figures in the cultivated soil show considerable fluctuations, particularly in the 0- to 2-inch horizon, reaching a peak of 175 p.p.m. on March 6th and showing a trace on June 15th. In the upper horizon of the cultivated soil the mean nitrate figure was 135 p.p.m. on February 23rd, and subsequently fell to 111, and then increased to 175 p.p.m. on March 6th. It fell again to 119 p.p.m. on March 28th and then increased to another peak of 134 p.p.m. on April 18th. Thereafter it decreased sharply to 36 p.p.m. on May 16th and to a trace on June 13th. The Figures for the lower depth of the cultivated soil sampled decreased from 66 p.p.m. on March 28th to 52.5 and 33 p.p.m. on April 18th and May 16th respectively and to 1.7 p.p.m. on June 13th.

At no time throughout the course of this investigation was the mean nitrate figure in grassland recorded above 15 p.p.m. for the top two inches and the average of all the upper horizon grassland samplings was 10.7 p.p.m. In the upper horizon the mean figure decreased from 14 p.p.m. on February 23rd to 9 p.p.m. on March 5th. From the peak of 15 p.p.m. on May 16th it fell sharply to the lowest value of 4.6 p.p.m. on June 13th. The mean nitrate figures for the lower depth show a marked similarity in trend to those of the upper horizon. From 8 p.p.m. on March 28th there is a decrease to 3 p.p.m. on April 18th then an increase to 12.9 p.p.m. on May 16th followed by another fall to 2.6 p.p.m. on June 13th.

The analyses of variance of the nitrate figures are summarised as follows, where the symbols used are N.S. = not significant at 5% level, S = significant at 5% level but not at 1% level and H.S. = significant at 1% level of probability.

Date	Between Treatments		Between Depths		Interaction		Error d.f.
	F	Result	F	Result	F	Result	
Feb. 23	-	-	-	-	-	-	-
Feb. 25	134.80	H.S.	-	-	-	-	21
Mar. 6	83.06	H.S.	-	-	-	-	16
Mar. 28	97.63	H.S.	10.78	H.S.	5.54	S	9
Apr. 18	48.17	H.S.	12.15	H.S.	9.04	S	9
May 16	12.89	H.S.	2.00	N.S.	0.04	N.S.	9
June 13	0.10	N.S.	17.94	H.S.	0.00	N.S.	9

This shows that,

1. For individual dates, there were differences between treatments as follows:

February 25th, March 6th, March 28th, April 18th and May 16th the nitrate status under clean-cultivation was higher than that under grassland.

On June 13th there was no significant difference in nitrate status between clean-cultivation and grassland.

2. Comparing differences due to depth of sampling, on March 28th and April 18th the nitrate status of the upper horizon sampled was higher than that of the lower horizon. However, on June 13th the nitrate status of the lower horizon was higher than that of the upper horizon sampled.

3. There was a significant interaction between treatments and depths for March 28th and April 18th. This means that on these dates the effect of depth on nitrate was different for both treatments - in this case, the upper horizon of the clean-cultivated soil had a higher proportionate accumulation of nitrate in relation to the lower horizon than the upper horizon of the grassland soil had in relation to its respective lower horizon.

There was no significant relationship between the mean soil ammonia and nitrate figures under either treatment or at either of the two depths sampled.

SOIL pH

The means for both treatments at the two depths sampled are given in Table V and shown graphically in Figure IV.

Fig. IV. The seasonal fluctuations in soil temperature, moisture and pH and the amount of rainfall received. The following symbols are used: CC.1 = clean cultivation at 0- to 2- inches depth, CC.2 = clean cultivation at 2- to 4-inch depth, GR.1 = grassland at 0- to 2-inch depth, and GR.2 = grassland at 2- to 4- inch depth.

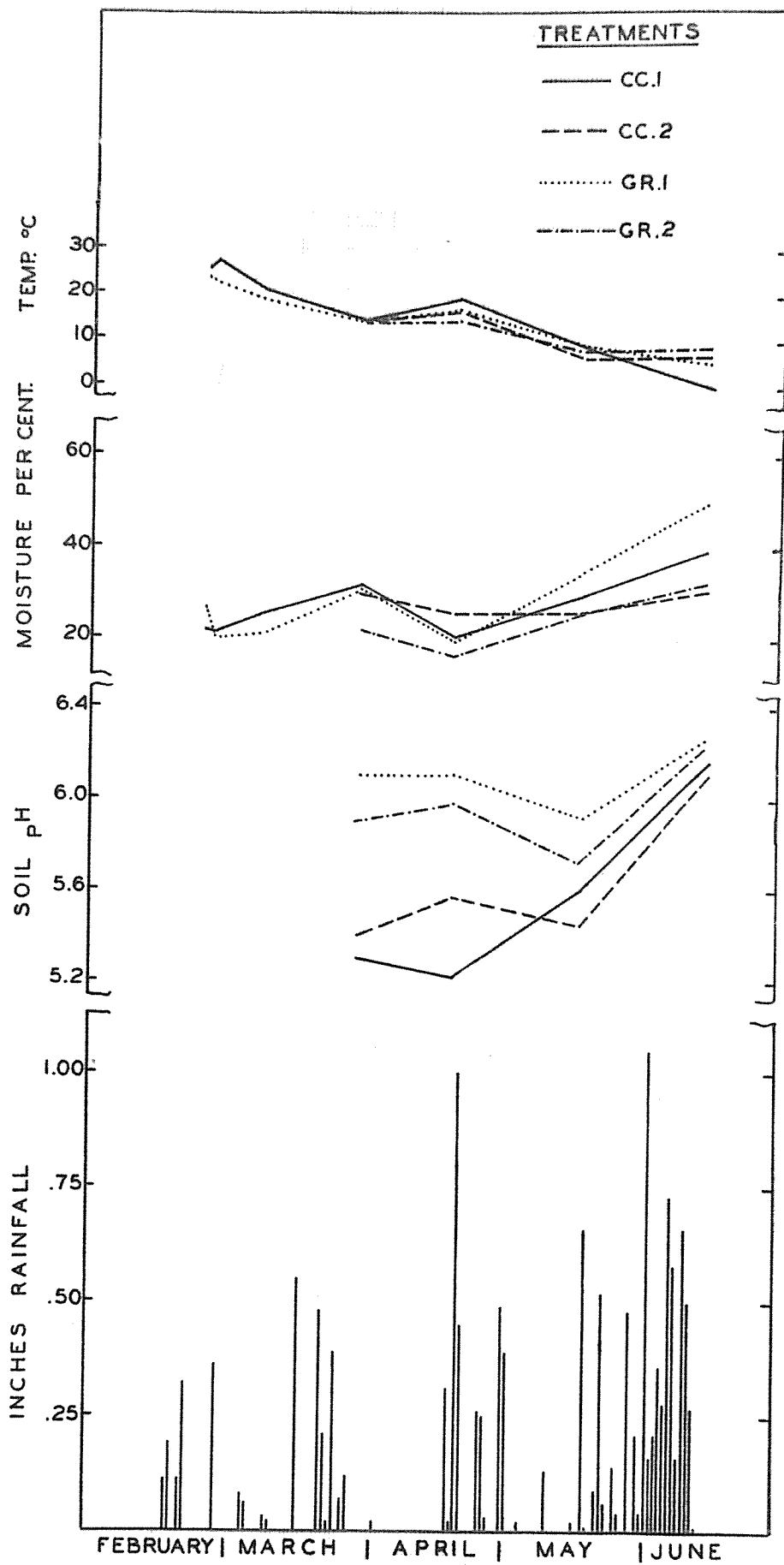


Table V

Mean Soil pH Values

Date	Cultivated		Grassland	
	0" - 2"	2" - 4"	0" - 2"	2" - 4"
March 28	5.30	5.40	6.10	5.90
April 18	5.22	5.47	6.10	6.08
May 16	5.60	5.45	5.92	5.73
June 13	6.16	6.11	6.26	6.23

Fluctuations were greatest in the pH figures for the upper horizon of the cultivated soil, (range pH 5.22 to 6.16) and least in those for the upper horizon of the grassland soil (pH 5.92 to pH 6.26). The figures for the lower depth of both cultivated and grassland soil show fluctuations within the range of those for the surface samples. Towards the end of the investigation on June 13th the figures for all treatments converged with that of the surface horizon of the grassland sample showing a mean value of pH 6.26, the lower grassland sample at pH 6.23, the upper cultivated soil 6.16 and the lower cultivated soil 6.11.

The analyses of variance of the pH figures are summarised as follows, where N.S.=not significant at 5% level, S=significant at 5% level but not at 1% level and H.S.=significant at 1% level of probability:

Date	Between Treatments		Between Depths		Interaction		Error d. f.
	F	Result	F	Result	F	Result	
Mar. 28	112.14	H.S.	0.00	N.S.	2.86	N.S.	9
Apr. 18	204.01	H.S.	7.83	S	6.85	S	9
May 16	20.44	H.S.	1.58	N.S.	1.29	N.S.	9
June 13	3.67	N.S.	0.46	N.S.	0.26	N.S.	9

This shows that,

1. Differences due to treatment existed in soil pH values on March 28th, April 18th and May 16th, when the figures for the clean-cultivated soil were significantly lower than those for grassland.

2. On only one date April 18th was there a difference in soil pH between the two depths sampled. On this date the pH of the upper horizon of the cultivated soil was significantly lower than that of the lower horizon.

3. On the same date, April 18th, there was a significant interaction between treatment and depth - that is on this date the effect of depth on soil pH was different for both treatments. As has already been shown, the pH of the upper horizon of the clean-cultivated soil was lower than that of its respective lower horizon, while under grassland there was no difference in pH values between the two horizons.

The relationship between soil pH and the mean nitrate figures for both treatments at both depths sampled is shown by reference to Figure V. On analysis, the negative straight-line regression of pH on the logarithm of the mean nitrate figures, (in parts per million) was found to be highly significant. (Table VI).

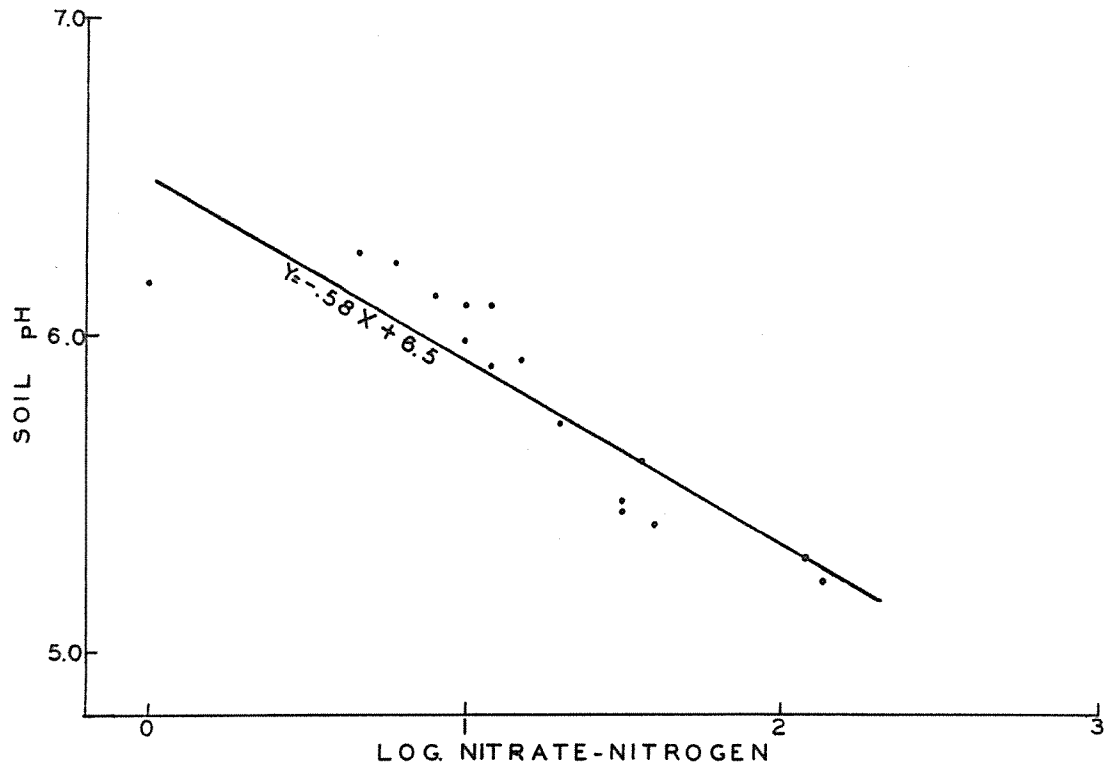


Fig. V. The relationship between soil nitrogen and soil pH.

Table VI

Regression of soil pH on log. nitrate

Analysis of Variance "F" Test

Source	S.S.	d.f.	M.S.	F	5%	1%	Result
Due to Regression	1.427	1	1.427	33.13	4.60	8.86	H.S.
Error	0.603	14	0.043				
Total	2.030	15					

The regression equation calculated by the method of least squares was $y = -.58x + 6.5$, where y is the dependent variable (soil pH) and x is the independent variable (log. nitrate-nitrogen).

This means that soil pH variations were due to fluctuations in soil nitrate-nitrogen, a unit decrease in pH value being caused by a logarithmic increase in soil nitrate.

SOIL TEMPERATURE

Soil temperature readings were made at 10 a.m. on the date of sampling, and are recorded in Table VII and Figure IV.

Table VII

Mean Soil Temperature °C

Date	Cultivated		Grassland	
	1"	3"	1"	3"
February 23	25.5	-	23.5	-
February 25	27.0	-	22.0	-
March 6	21.0	-	19.0	-
March 28	14.0	14.0	14.0	14.0
April 18	19.0	16.0	16.5	14.5
May 16	8.8	6.8	9.0	8.4
June 13	0	7.0	5.0	9.0

Soil temperature readings for the surface horizon of both cultivated and grassland soil show similar trends, starting at 25.5 and 23.5°C respectively on February 23rd, and showing a gradual decrease to zero and 5°C respectively on June 13th, interrupted only by a second peak on April 18th of 19.0 and 16.5°C respectively. The readings for the lower horizon closely follow those for the surface horizon, being as much as 3°C lower in the cultivated soil on April 18th, yet 7 and 4°C higher for the cultivated and grassland respectively on June 13th.

SOIL MOISTURE

Soil moisture figures are given in Table VIII and shown graphically in Figure IV.

Table VIII

Mean Soil Moisture. Percentage of Dry Soil

Date	Cultivated		Grassland	
	0" - 2"	2" - 4"	0" - 2"	2" - 4"
February 23	23.8	-	27.3	-
February 25	23.0	-	21.0	-
March 6	25.0	-	22.0	-
March 28	33.5	30.0	33.1	23.5
April 18	20.6	25.4	19.9	17.7
May 16	29.2	27.4	35.0	27.3
June 13	39.4	31.7	50.3	32.8

Soil moisture figures for the surface horizon of both cultivated and grassland soil show closely similar trends, having minimum values of 20.6 and 19.9 per cent respectively on April 18th, and maximum values of 39.4 and 50.3 per cent respectively on June 13th. The curves

showed an initial slight decrease on February 25th followed by an increase to a peak on March 28th, followed in turn by a drop to the minimum values quoted above, after which there is a continued increase to the maximum values. The lower depths show similar but smaller fluctuations, having minimum values of 25.4 per cent and 17.7 per cent for the cultivated and grassland soil respectively on April 18th, and maximum values of 31.7 and 32.8 per cent respectively on June 13th.

RAINFALL RECORDS

Monthly rainfall records are summarised in Table IX and are presented graphically in Figures II and III.

Table IX

Monthly Rainfall 1952

Month	Inches Rain
February	1.94
March	2.03
April	2.83
May	2.81
June	7.76

From February 23rd to the end of that month, 0.36 inches of rain were recorded, all on 27th. Between February 27th and March 6th only 0.14 inches fell. A long almost rainless period with only 0.02 inches recorded, occurred from March 29th until April 18th when 0.31 inches were recorded. Another almost rainless period occurred when only 0.17 inches were recorded

between May 2nd and May 17th. From then on, rain fell on all except two days until June 13th, the heaviest fall being 1.05 inches recorded on June 1st and the total for the first two weeks of June being 4.95 inches.

CHAPTER V

DISCUSSION

As a result of this investigation, the effect of the grass sward in suppressing nitrate accumulation is clearly evident from a comparison of the curves for the grassland samples with those of the clean-cultivated soil. The cause of this suppression was not investigated but has been attributed by other workers to one or more of the following factors, rapid uptake of nitrate by the herbage, greater numbers of micro-organisms and therefore greater utilisation of nitrate, or an effect of the plant in depressing nitrification, either by reducing the soil moisture or by a direct effect.

The results of the present investigation do not provide an adequate basis for evaluating the importance of these possible contributing factors.

If the lower nitrate values under grassland were due to greater utilisation of nitrate than under the clean-cultivated soil then it would be expected that ammonia accumulation under the former would also be suppressed. The figures presented show that on only two occasions were the mean ammonia values for the clean-cultivated soil significantly higher than those for grassland, while on one later date the reverse was the case.

The findings of Richardson (1933, 1935) and others that in grassland soils the ammonia level was consistently

higher than the nitrate level was not supported. This may perhaps have been due to the dominance of white clover in the sward used in the present investigation, having some striking effect on the soil ammonia/nitrate relationships.

The high nitrate figures from the clean-cultivated plots, particularly in the earlier samplings, were no doubt due to the rapid decomposition and nitrification of the plant residues that had been worked into the soil only a few weeks before the first samples were taken. These high values were reflected in the samples from the 2- to 4-inch horizon, though in this case they may have accumulated as a result of leaching of nitrate from the surface soil.

Evidence has been presented to show that generally both ammonia and nitrate values are lower for the lower horizons sampled than for the respective surface horizon samples. Thus ammonia and nitrate accumulation tend to decrease with depth under both grassland and cultivated soil. This is presumably due to less favourable conditions for micro-organic activity at the lower depths, through one or more of the following factors: poor aeration, differences in soil moisture, lower temperatures, a decrease in the more readily decomposable organic matter or to some other factor.

The effect of soil temperature on the level of the mean soil ammonia values is of interest. The regression

equation shows that the logarithm of the ammonia value increased by 0.35 for each unit increase of soil temperature, in Centigrade units, within the limits of the data in the present investigation. Thus it appears that a soil temperature increase, by encouraging microbial activity caused a greater "ammonia pressure" and so an increase in the ammonium status of the soil. This effect is exactly similar to that described by Richardson (1938), of liming grass plots.

Another interesting result of this investigation is the relationship shown between soil pH and soil nitrate. This result is not in complete accord with the results shown by Lehr (1950), although he found an approximately linear relation between pH and nitrate on uncropped soil. The comparatively large decrease in pH may have an important effect on crop growth or pest and disease resistance if the initial pH level is at all critical. On the other hand nitrification may be temporarily inhibited by such decreases, so that ammonia accumulates and the pH will be then raised away from the critical level.

The effects of the seasonal factors, rainfall, soil moisture and soil temperature on ammonia and nitrate accumulations have been shown.

Rainfall resulted in an immediate depression of the nitrate status in the cultivated soil due to leaching, though the level was soon regained under favourable conditions, such as occurred in the earlier part of the

investigation. Rainfall appeared to have little direct effect on the ammonia status.

The significance of the results of the present investigation with particular reference to fruit-tree nutrition are difficult to interpret as the study was not directly associated with fruit-trees, and therefore the results must be applied in the light of present knowledge of fruit-tree nutrition.

Experiments at Woburn (Bedford and Pickering, 1911; Pickering, 1917) showed that grass and weeds growing in orchards resulted in greatly reduced growth of the trees with consequent deleterious effects on fruiting. Pickering dismissed suggestions that the effect was due to competition for water and nutrients, but concluded that it was due to the excretion by the grass of some substance toxic to the trees. Such toxic excretions were never isolated.

Further research by Rogers and his associates at East Malling (Rogers et al. 1948) has shown that the harmful effects of grass culture in cool humid climates are due mainly to nitrogen deficiency. Whether or not this deficiency is caused merely by severe competition between the trees and the grass plants for the available soil nitrogen, or whether it is due to an effect such as proposed by Theron (1951) has not yet been established.

The effect of a permanent grass cover on fruit-tree nutrition has been attributed by Theron (1951) to be due

not to a competition between the grass cover and the trees for nitrates but rather to an inhibition of nitrification through the grass roots effecting a paralysis of the autotropic dehydrogenase system of the nitrifying organisms.

The present study has shown that the mineral nitrogen status of the soil under a grass sward treated to simulate orchard practice, was lower and subject to less violent fluctuations than comparable areas that were clean-cultivated. Just how this lower ammonia and nitrate status would affect tree growth has not been investigated but apple, pear, plum and peach trees growing in grass on a site, adjacent to the area used in this investigation showed no deleterious effects of growth and cropping. The practice of clean-cultivation under conditions comparable to those of the present study appears to be suited to newly planted orchards, as it provides ideal conditions for growth when the organic matter content of the soil is high. Unfortunately if cultivation is continued it leads to very rapid destruction of the organic matter.

As the clean-cultivated plots were established by breaking up grassland only a short time before the first samplings were made, the ammonia and nitrate figures were not a true reflection of the values to be expected from a long established cultivated area under otherwise comparable conditions. Nitrification can only occur at the expense of the total soil nitrogen supply and therefore cannot be maintained at a high level unless the reserve supply of

nitrogen is maintained.

In the main the problems of grass orcharding in humid climates appear to be those of maintaining an adequate and available nitrogen supply to the trees. The importance of legumes in swards is recognised, but Rogers and Greenham found that supplementary nitrogen fertilizers were necessary for English conditions in order to maintain a satisfactory level of growth in the trees.

CHAPTER VI

SUMMARY

A brief critical review has been made of overseas work on ammonia and nitrate fluctuations under various management systems and in various seasons.

Seasonal variations in soil ammonia and nitrate have been followed during the period February to June 1952 under two different orchard soil management systems viz clean-cultivation and permanent grassland, and in two successive two-inch horizons.

Figures have been presented to show that nitrate accumulation was significantly depressed under a mixed grass/clover herbage when compared with cultivated soil. However, ammonia accumulation showed little variation between the two treatments. Both ammonia and nitrate accumulation in the deeper horizons was significantly lower than in the surface horizons for the respective treatments.

Soil pH values have been shown to be affected by nitrate accumulation, there having been a significant relationship between the logarithm of the mean nitrate values and soil pH.

The effects of soil moisture, soil temperature and rainfall on ammonia and nitrate accumulation have been studied. A highly significant logarithmic relationship has been shown between soil temperature and the mean ammonia figures. Rainfall caused an immediate reduction in the nitrate values in

the clean-cultivated soil, but the status was regained quickly under conditions favourable for nitrification.

An attempt has been made to relate the result of the present investigation to fruit-tree nutrition in the light of present knowledge of the subject.

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PART TWO

CHAPTER I

INTRODUCTION

The problem of maintaining fertility in orchard soils in temperate climates largely centres around the nitrogen supply. Soil management practices have been shown to have a considerable effect on the mineral nitrogen level, but the customary method of supplying nitrogen to orchard soils is by the addition of nitrogenous fertilizers.

The comparative behaviour of ammonia and nitrate added to orchard soils has not been studied previously in this country, and in view of the importance of influencing the soil nitrogen level by applying nitrogenous fertilizers and owing to the absence of any previous experiments on this problem the following investigations were made.

1. A study was made of the mobility of three inorganic nitrogen fertilizers added in autumn to bare cultivated soil. In addition, records were taken of comparative fluctuations in soil pH during the time of nitrogen disappearance.
2. An investigation was made to follow the movement and disappearance of mineral nitrogen following the application of sulphate of ammonia at 3 cwt. and 9 cwt. per acre to grassland in spring, to simulate the orchard practice of broadcast and band application of fertilizers.

CHAPTER II

REVIEW OF THE LITERATURE

MOVEMENT OF NITROGEN ADDED TO BARE SOIL

It has long been established that nitrogen added as ammonium salts to the soil surface is held there by the cation-exchange phenomenon until nitrification occurs with its subsequent release of ammonium-nitrogen as nitrate-nitrogen which is readily mobile in soils.

Smith (1928) studied nitrate distribution at various depths for a Rhode Island silt-loam soil after incorporating various nitrogen fertilizers in the top 7 inches. In fallow soil he found disappearances of nitrate due to rainfall and microbial activity, but little total loss from the upper two feet over the whole season. Nitrates leached by percolating rain-water were often retained in the subsoil layers and returned by the upward movement of soil water under mid-summer conditions.

Krantz et al. (1943) in America found that when ammonium sulphate was ploughed under, a large proportion of the applied nitrogen remained as ammonia in the moist root zone throughout the growing season. The addition of lime, phosphorus and potassium increased biological activity and temporarily tied up more of the applied ammonia.

Sarazin (1939) at Versailles found that nitrification took place at temperatures below 5°C. and that over a ten-year period, almost all the nitrogen applied as sulphate of

ammonia to bare ground at the rate of about 130 pounds of nitrogen per acre in autumn had disappeared by spring, apparently through nitrification and leaching of the nitrates to below 20 centimetres, the lowest limit of sampling.

Jenny et al. (1944-45) found improved water penetration on irrigated heavy Californian soils of the montmorillonite clay type after treatment with sulphate of ammonia. This behaviour was anticipated on theoretical grounds as they believed sulphate of ammonia to have high flocculating powers.

Collison and Walker (1916) found that the nitrogen from nitrate of soda applied to young orange trees leached more rapidly and in greater amounts than that supplied in sulphate of ammonia or dried-blood.

Russell (1950) stated that nitrogen lost by leaching could be sufficient to account for the total loss of nitrogen from bare fallow soils under English conditions.

In discussing the residual effect of nitrogen fertilizers Crowther (1946) commented as follows:

"It is well established by careful experiment and by practical experience that most nitrogen fertilizers have little residual effect in the following year. Whatever form is added, the bulk of any residue is washed out as nitrate during the winter in the humid temperate climate of Great Britain."

MOVEMENT OF AMMONIA ADDED TO GRASSLAND

The available literature on this topic comprises only the records of the investigations of Richardson (1933, 1935 and 1938), and Eggleton (1934, and 1935).

Richardson (1933) found a rapid disappearance of ammonia added to grassland soils in early winter or early spring. As very little nitrate was found in the soil at any time, Richardson concluded that some of the added nitrogen must have been taken up directly by the grass without nitrification. Richardson (1935, 1938) later confirmed this work finding equilibrium levels for nitrate and ammonia under grassland subject only to minor fluctuations and where the half-period for reaching equilibrium after the addition of nitrogenous fertilizers was only a few days or one to two weeks at the most in winter time. Thus the addition of a nitrogen fertilizer to grassland upset the equilibrium level for only a very short time.

Eggleton (1934, 1935) found that the rate of transformation or uptake of ammonia added as sulphate of ammonia to grassland, was controlled in early spring by low soil temperature, while in mid-summer, soil moisture was the limiting factor. When moisture conditions and temperature were both favourable, the excess of added ammonia almost completely disappeared in three or four days, being accompanied in all cases by a definite, though smaller increase in nitrate-nitrogen.

Subsequent to the application of sulphate of ammonia,

the ammonia and nitrate status were both at a lower level than in the unfertilized soil. Eggleton ascribed this to sulphate of ammonia lowering the rate of ammonification from organic matter and supported this conclusion by the fact that the numbers of total soil bacteria were significantly depressed in the nitrogen-treated plots. This, he suggested, was probably due in part to the more acid reaction of the nitrogen-treated soil, and partly to the somewhat lower moisture content due to the greater amount of water transpired from the larger amount of grass leaf surface. This last factor does not seem to be important if regard is taken of the more recent transpiration theories of Penman (1949, 1952).

EFFECT OF NITROGEN FERTILIZERS ON SOIL pH

The effects of nitrogen fertilizers on the base status and on soil reaction have been reported and discussed by many workers. Most attention appears to have been given to the effects of sulphate of ammonia, less to nitrate of soda and very little to the other inorganic nitrogen fertilizers.

Following earlier observations, initially by Liebig and then by Thompson (1850), Way (1850, 1852) established the existence of base exchange in soils and showed that soils could absorb ammonia to displace an equivalent amount of calcium or other bases. Way also showed that ammonia was held in the soil against leaching but that nitrates were not. The mechanism by which this took place was not

then known, but he suggested that base absorbing power existed only in clays and not in organic matter or sands.

Numerous lysimeter experiments have since been conducted particularly by American workers (Ruprecht and Morse, 1915; Collison and Walker, 1916; Morgan, 1936; Morgan and Bailey, 1938 and others). The results all clearly demonstrated the marked depletion of exchangeable calcium resulting from the use of sulphate of ammonia and the consequent decrease in soil pH.

It has long been known that the use of sulphate of ammonia leads to conditions of soil acidity. The early investigators believed that the acidifying effect of sulphate of ammonia was due solely to its production of sulphuric acid.

One of the first examples recorded of a soil becoming acid through a particular course of treatment was by Voelcker (1901). He observed that the soil of the permanent wheat and barley plots at Woburn which had been receiving ammonium salts alone for about twenty years had become "actually acid to litmus paper". The acidity thus developed rendered the land unable to carry barley, though its capacity to do so was restored by a simple dressing of 2 tons per acre of lime.

Hall (1909) at Rothamsted showed a direct relation between the application of ammonium fertilizers and the loss of calcium in drainage water. Using a mixture of

sulphate and muriate of ammonia he showed, in one case, that 117 lbs. of calcium carbonate were removed for each 200 lbs. of the ammonium salt applied. In discussing leaching experiments, he remarked: "On sands the ammonium salts had no action, with clay an interchange of bases between the salts and the zeolites took place but the resulting liquid remained perfectly neutral as would be expected on purely chemical grounds."

Following applications of ammonium salts, (a mixture of sulphate and muriate of ammonia), Hall found an increase in the amount of comparatively insoluble free humic acid. He stated, "Clearly this had arisen by the action of the mineral acids set free year by year from the ammonium salts, upon the neutral humus or calcium humate originally present in the soil, and humic acid had been able to accumulate because it is but slightly soluble in water." He thus reasoned "It became pretty clear that the acidity of the Rothamsted grass soils had arisen from the action of the various micro-fungi upon the ammonium salts that had been annually applied to these plots; such fungi have become very abundant in the soil and are able to attack ammonium salts and set free the acid, taking the ammonia to themselves to supply the nitrogen they require for nutrition".

Hall suggested also that nitrifying bacteria were completely inhibited by a very slightly acid medium (the degree of acidity is not recorded), and ascribed the cause of infertility on acid soils to the competition by the fungi

with higher plants for applied manures, and to the absence of nitrification. Nitrification was not considered to be a factor in creating conditions of greater acidity in an already acid soil.

Lawes, Gilbert and Warington (1882) referred to the existence of the process of nitrification, although the responsible organisms were not then isolated, and they showed that the oxidation of ammonia to nitric acid involved the subsequent loss of calcium and other bases. They suggested that the addition of 400 lbs. of ammonium salts would result in the removal of about 172 lbs. of lime in combination with the sulphate and chloride of the ammonium salts and a further loss of 172 lbs. of lime would occur on nitrification of the ammonia and the removal of nitrates in drainage-water.

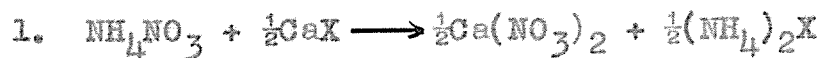
Later, Page (1927) emphasized nitrification rather than loss of calcium in combination with sulphate as the cause of acidity developed by sulphate of ammonia, as the calcium is replaced in the exchange complex by another base, ammonium. The absorbed ammonium, he suggested, causes no change in soil reaction until it is nitrified to nitric acid.

In line with these views of Page, Pierre (1928) explained the acidifying effect of sulphate of ammonia as follows where "X" represents the absorbing complex:

1. $(\text{NH}_4)_2\text{SO}_4 + \text{CaX} \rightarrow \text{CaSO}_4 + (\text{NH}_4)_2\text{X}$
2. $(\text{NH}_4)_2\text{X} + \text{O}_2 \xrightarrow{\text{nitrification}} 2\text{HNO}_3 + \text{H}_2\text{X} + 2\text{H}_2\text{O}$
3. $2\text{HNO}_3 + \text{CaX} \rightarrow \text{Ca}(\text{NO}_3)_2 + \text{H}_2\text{X}$

As a result of the reaction represented in equation 1, no acidity is developed. Until nitrification, represented in equation 2 goes on, no acidity is developed. Then two molecules of nitric acid and one molecule of dibasic soil acid are formed. In equation 3, the nitric acid further reacts with another molecule of CaX. Thus, from one molecule of ammonium sulphate, two molecules of dibasic soil acid are eventually formed.

The effects of nitrate of ammonia on soil reaction were similarly explained by Pierre. Thus:



The $(\text{NH}_4)_2\text{X}$ then nitrifies as represented in the equations for ammonium sulphate, but since there is only one half as much to nitrify, only one-half the acidity will be developed.

On a chemical equivalent basis, the addition of 100 lbs. of sulphate of ammonia should be accompanied by the loss of 150 lbs. of calcium carbonate if all the nitrate is leached, and by 75 lbs. of calcium carbonate if none of the nitrates is leached. In practice, the loss of calcium carbonate comes in between these two limits. Pierre (1928) suggested that under cropped conditions, approximately one half of the nitrate intake by the plant was in the form of nitric acid, so that under conditions of complete removal of nitrate by cropping, sulphate of ammonia would develop 75 per cent of the theoretical acidity, that is, 120 lbs. of calcium carbonate lost for every 100 lbs. of sulphate of ammonia applied.

On the Rothamsted Park Grass plots and the Woburn Barley plots, Crowther (1925) demonstrated that long continued use of sulphate of ammonia led to a considerable increase in acidity up to a minimal pH value of 3.8, while the use of nitrate of soda gave a slight decrease in acidity. He also showed that the subsoil (9 to 18 inches) underwent changes similar to, but of less magnitude than those of the surface soil.

Pierre (1927) showed that the acidifying effect of physiologically acid fertilizers on soils with a low buffer capacity, such as sands, was more rapid and to a greater depth than those on heavy and organic soils with a higher buffer capacity.

Swanbeck and Morgan (1930) in investigating seasonal fluctuations in soil reaction, found a good general correlation between acidity and soil nitrate content, although decrease in acidity did not appear to take place as quickly as decrease in nitrogen content. They found that nitrate of soda produced an increased acidity over the no-nitrogen treatment for as long as any of the nitrate remained in the soil.

In discussing nitrate of soda, Hall (1909) commented as follows:

"The relation of nitrate of soda to the plant may be regarded as the simplest possible; we know that the compound need undergo no change in order to feed the plant, it can be taken up

directly and has a very immediate nutritive effect. Similarly it has but the slightest action upon the soil; nitrate of soda is not only readily soluble in water but it does not enter into combination with any of the soil constituents, and is therefore not retained, but is washed out at once when there is any drainage through the soil."

He suggested the existence of bacteria in the soil which take nitrogen from nitrate of soda, converting it into proteins and other body substances, and leaving behind the soda base combined with the carbon-dioxide which they excrete. "The process," he states, "is strictly comparable with the production of acid by the action of micro-fungi upon sulphate of ammonia."

CHAPTER III

EXPERIMENTAL MATERIAL AND METHODS

The area used for this study was of the Tokomaru silt-loam soil type and had been ploughed from grassland, rolled and levelled prior to the establishment of the experimental plots.

The investigation was conducted in two parts as follows:

1. A study of the comparative behaviour of three commercial inorganic nitrogen fertilizers, added to bare cultivated soil in autumn. This will be known as Experiment 1.
2. A study of the comparative behaviour of nitrogen added in sulphate of ammonia at two different rates of application to grassland in spring. This will be called Experiment 2.

EXPERIMENT 1

PLAN OF THE EXPERIMENT

The fertilizers used in this investigation were, sulphate of ammonia (20.6 to 21.0 per cent nitrogen), nitrate of soda (15.5 to 16.0 per cent nitrogen) and nitro-chalk (15.5 per cent nitrogen). All were applied to the soil surface at the rate of 140 lbs. of nitrogen per acre. The treatments were as follows:

- A. Control. No nitrogen fertilizer.
- B. Sulphate of Ammonia. 6 cwt. per acre

- C. Nitrate of Soda. $7\frac{3}{4}$ cwt. per acre.
- D. Nitro-chalk. $7\frac{3}{4}$ cwt. per acre.

The experimental plots were laid out in a 4 by 4 Latin Square, the plots being 6 feet by 3 feet in size, the total area of the experiment therefore being 24 feet by 12 feet. The design of the layout of the plots was as follows:

C	B	A	D
D	A	B	C
A	C	D	B
B	D	C	A

The plots were marked out, lightly hoed and raked level on 28th April. They were hoed and raked again on 3rd May, and after a broadcast dressing of superphosphate to the whole area at 2 cwt. per acre, they were raked again on 5th May. The fertilizers were weighed out mixed with dry sand as a carrier and distributed on 5th May, to the respective plots. Weed control was not carried out subsequently for fear of affecting the behaviour of the added nitrogen.

SAMPLING METHODS

Sampling was carried out between 9.30 and 10 a.m. 2, 4, 8, 15, 22, 29, 36, 43 and 71 days after the application of the fertilizers, the 71st day being on July 15th.

Each sample comprised 8 one-inch cores from each plot

taken at random with the sampler described by Fife (1944). It was decided to take one-inch soil cores in order to emphasize differences between treatments. Care was taken to avoid sampling from within about 4 inches of the edges of the plots. Thus 16 composite samples were taken on each sampling date. All samples were collected in screw-top glass jars and taken to the laboratory for analysis as soon after sampling as possible. On 17th June, 43 days after application, 6 successive one-inch cores were taken at 2 sampling points in each of the plots of Treatment A (Control) and Treatment B (sulphate of ammonia) to investigate the depth of penetration of the added ammonia.

CHEMICAL ANALYSIS - AMMONIA AND NITRATE

Ammonia was determined by Richardson's modification of Olsen's Method (Piper, 1942). A weighed quantity of soil is shaken up with 2 Normal potassium chloride solution 2 Normal hydrochloric acid and toluene, and the filtrate is distilled with fresh magnesia and the distillate collected in 0.04N H_2SO_4 . The excess of acid is titrated with approximately 0.04N sodium hydroxide using methyl red as indicator.

The amount of ammoniacal nitrogen present is given as mg. per kg. (parts per million) of dry soil.

Nitrate was determined from the residue remaining after the determination of ammonia. To the residue was added a small amount of finely powdered Devarda's alloy and the distillation was recommenced into a further quantity

of 0.04N sulphuric acid. The excess of acid was again titrated with approximately 0.04N sodium hydroxide using methyl red as indicator.

The amount of nitrate nitrogen present is expressed as mg. per kg. (parts per million) of dry soil.

SOIL pH DETERMINATIONS

Starting on March 28th, pH determinations were made on fresh soil samples within a few hours of sampling, using a Cambridge pH meter and a glass electrode filled with saturated potassium chloride solution. Determinations were made on a 1:2½ soil:water suspension allowed to stand for at least a quarter of an hour.

MOISTURE DETERMINATION

Moisture was determined by drying 50 grams of the sample for 16 to 24 hours in an electric oven at about 105°C. Moisture is expressed as the number of grams of moisture lost on drying per 100 grams of dry soil.

SOIL TEMPERATURE RECORDS

At the time of sampling, soil temperature readings were made at a half-inch depth for each plot sampled, using ordinary glass laboratory thermometers pushed into the ground to the appropriate depth.

Soil temperatures are expressed in Centigrade units.

RAINFALL RECORDS

Rainfall figures were taken from the Meteorological

records of Grasslands Division, D.S.I.R., Palmerston North. Rainfall was recorded at 9 a.m. and entered for the previous day.

Rainfall figures are given in inches and points.

STATISTICAL ANALYSIS

All figures were subjected to an analysis of variance using Snedecor's "F" test, to determine significant ($p = .05$) and highly significant ($p = .01$) differences between treatments, depths and sampling dates. (Snedecor, 1940).

Where relevant, simple linear regression analyses were made to determine the existence of significant and highly significant relationships between groups of data (Fisher, 1948). The line given by the regression equation $y = a + bx$ was fitted to the data by the method of least squares.

Where there were more than two variates with mutual relationships, multiple regression analyses were made. (Fisher, 1948). The plane given by the regression equation of the type $y = a + b_1x_1 + b_2x_2$ was fitted to the data by the method of least squares. (Snedecor, 1940).

EXPERIMENT 2

PLAN OF THE EXPERIMENT

The treatments used in this investigation were commercial sulphate of ammonia (20.6 to 21 per cent nitrogen) at 3 cwt. and 9 cwt. per acre to simulate broadcast

application and concentrated band application respectively.

The experimental area was originally designed as a 4 by 4 Latin Square to investigate the effect of the treatments in both grassland and cultivated soil. Each plot was 6 feet by 6 feet in size and the total area was therefore 24 feet square. The grass plots were established as follows.

The area was marked out, lightly hoed and a broadcast dressing of superphosphate at the rate of 2 cwt. per acre was raked in on 3rd May. A seeds' mixture composed by weight of 8 parts short rotation ryegrass (*Lolium hybrid* spp.), 3 parts Italian ryegrass (*Lolium multiflorum*), 1 part cowgrass (*Trifolium pratense*) and 1 part white clover (*Trifolium repens*) was sown on May 11th at the rate of approximately 130 lbs. per acre and lightly covered in by raking. A broadcast application of lime at 4 cwt. per acre over the whole area was also made on this date.

The "cultivated" plots were not used in this investigation as it was desired to study the movement of mineral nitrogen at 2 successive depths under grassland only, and the time available did not permit more than 16 composite samples being taken for analysis. The fertilizer was weighed out and applied to the respective grass plots, mixed with dry sand as a carrier on 11th August. The layout of the experimental area was as follows:

9	cultivated	cultivated	3
3	cultivated	9	cultivated
cultivated	9	3	cultivated
cultivated	3	cultivated	9

SAMPLING METHODS

Sampling was carried out between 9.30 and 10 a.m. on 4, 10, 20 and 30 days after application. At the 30th day, that is, on September 10th, the collection of samples was discontinued. Each sample comprised 6 3-inch cores from each plot taken at random with the sampler described by Fife (1944). Care was taken to avoid sampling from within about 6 inches of the edges of the plot. At each sampling point, 2 successive 3-inch cores were removed, thus giving 16 composite samples in all, from 0- to 3- and 3- to 6-inch horizons. All samples were collected in screw-top glass jars and taken to the laboratory as soon after sampling as possible for analysis.

CHEMICAL ANALYSIS - AMMONIA AND NITRATE

Ammonia and nitrate were determined by the method previously described.

SOIL MOISTURE

Soil moisture was determined by the method previously described.

SOIL TEMPERATURE

At the time of sampling, soil temperature readings were made at $1\frac{1}{2}$ -inch and $4\frac{1}{2}$ inch depths for each plot sampled, by the method previously described.

RAINFALL RECORDS

Rainfall figures were taken from the Meteorological records of Grasslands Division, D.S.I.R., Palmerston North, at a location within a half mile of the experimental area.

STATISTICAL ANALYSIS

Statistical analyses were made, where relevant, between groups of data, by methods previously described.

CHAPTER IV

EXPERIMENTAL RESULTS AND ANALYSIS

EXPERIMENT 1

AMMONIA

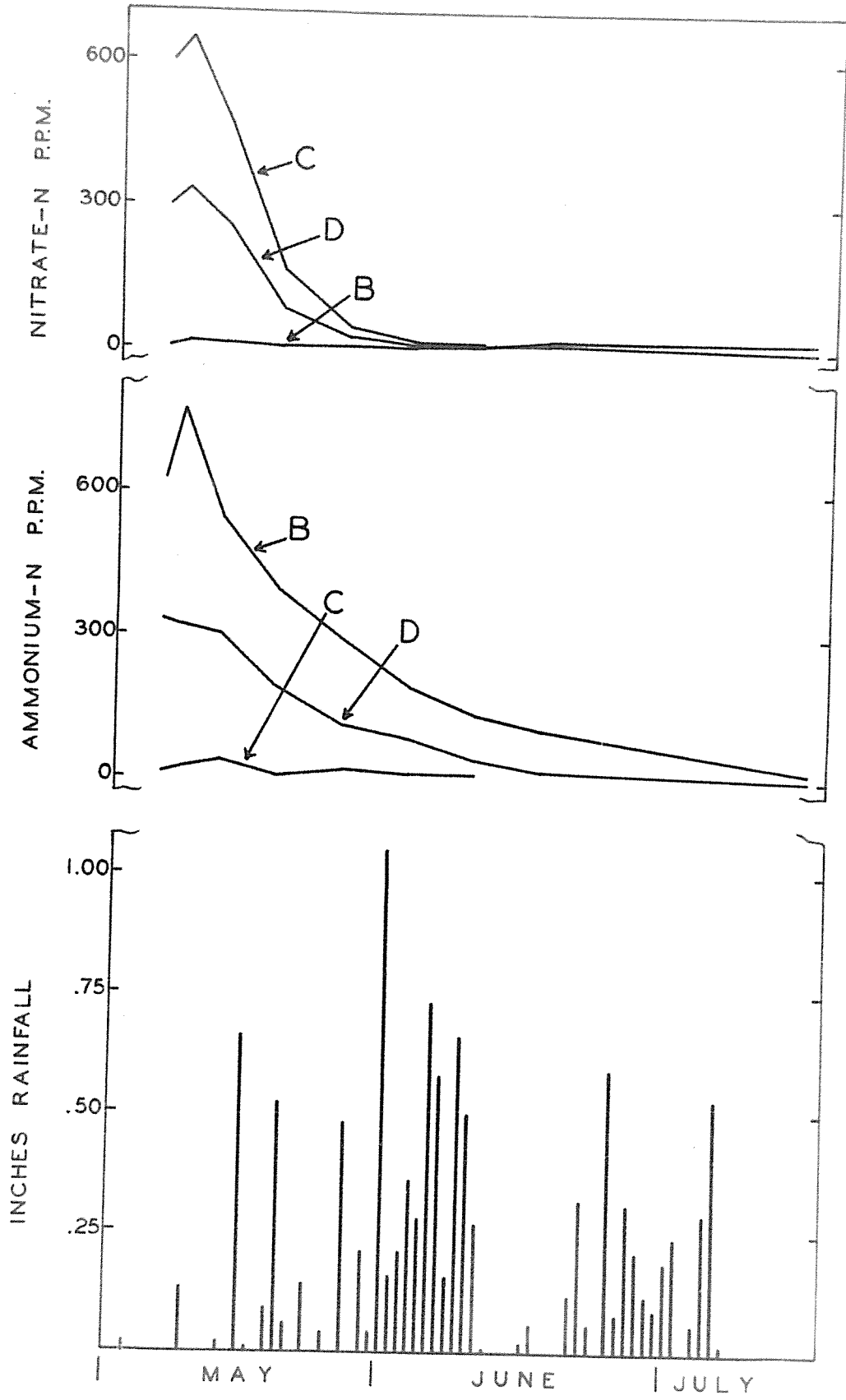
The means for all treatments and the control from each sampling are given in Table X and shown in Figure VI, which represents the differences between the treatment values and the control values. Taking differences had the effect of eliminating those natural variations which are common to all plots, so that the residual figures represent true treatment values. Reference to "treatment" value in future discussion should be taken to mean observed treatment figure minus that for the control.

TABLE X

MEAN AMMONIUM-NITROGEN (P.P.M.)

DAYS	T R E A T M E N T			
	A	B	C	D
2	93	716	99	426
4	72	841	95	394
8	52	593	89	353
15	55	446	60	243
22	15	303	35	125
29	4	197	16	84
36	4	137	12	44
43	0	104	-	17
71	8	27	-	9

Fig. VI. Soil ammonium and nitrate-nitrogen following the application of nitrogenous fertilizers, and the rainfall received. The symbols used are as follows: B = sulphate of ammonia, C = nitrate of soda and D = nitro-chalk.



The figures for treatments B and D show sharp decreases at first (except for a pronounced rise on the 4th day for treatment B), followed by a gradual falling off in the rate of decrease with increase in time^{after} application.

The analyses of the results from the Latin Square method using Snedecor's F test (Snedecor, 1940) and Fisher's t test (Fisher, 1948) appear in Table XI, where the following symbols are used.

H.S. = Significant at 1% level of probability

(d = .05) = value required for difference between means at 5% level

(d = .01) = value required for difference between means at 1% level

A > B = the mean of A is greater than that of B at 5% level

A >> B = the mean of A is greater than that of B at 1% level

TABLE XI
ANALYSIS OF AMMONIA RESULTS

DAY	ANALYSIS OF VARIANCE			DIFFS. BETWEEN MEANS t TEST			
	F	Result	Error d.f.	(d=.05) Result	(d=.01) Result		
2	115.02	H.S.	6	84.8	B>D>(A,C)	122.4	B>>D>>(A,C)
4	107.62	H.S.	6	105.3	B>D>(A,C)	147.6	B>>D>>(A,C)
8	93.16	H.S.	6	114.5	B>D>(A,C)	160.5	B>>D>>(A,C)
15	157.34	H.S.	6	46.2	B>D>(A,C)	66.5	B>>D>>(A,C)
22	367.29	H.S.	6	29.9	B>D>(A,C)	41.9	B>>D>>(A,C)
29	181.23	H.S.	6	62.8	B>D>(A,C)	86.1	B >> (A,C,D)
36	79.40	H.S.	6	24.3	B>D>(A,C)	35.9	B >> (A,C,D)
43	133.41	H.S.	6	13.1	B>D>A	18.6	B >> (A,D)
71	14.67	H.S.	6	7.3	B > (A,D)	10.3	B >> (A,D)

This shows that,

1. The residue of ammonia supplied in sulphate of ammonia was significantly greater in amount in the top one-inch of soil, than that supplied in nitro-chalk, and significantly greater than the ammonia in the no-nitrogen treatment, even at 71 days after application.
2. The residue of ammonia supplied in nitro-chalk was significantly greater in amount in the top one-inch of soil than that in the no-nitrogen treatment, up to the 43rd day.
3. At no time throughout the course of the experiment was ammonia accumulation in the nitrate of soda plots significantly greater than that in the no-nitrogen treatment.

A highly significant regression of the logarithms of the mean ammonia values of the sulphate of ammonia and nitro-chalk treatments on time was found. (Tables XII and XIII). These are shown graphically in Figure VII.

TABLE XII

Regression of log. ammonia on days after application

Sulphate of Ammonia							
Source	SS	d.f.	M.S.	F	5%	1%	Result
Due to regression	2.0365	1	2.0365	485.10	5.59	12.25	H.S.
Error	0.0291	7	0.0042				
Total	2.0656	8					

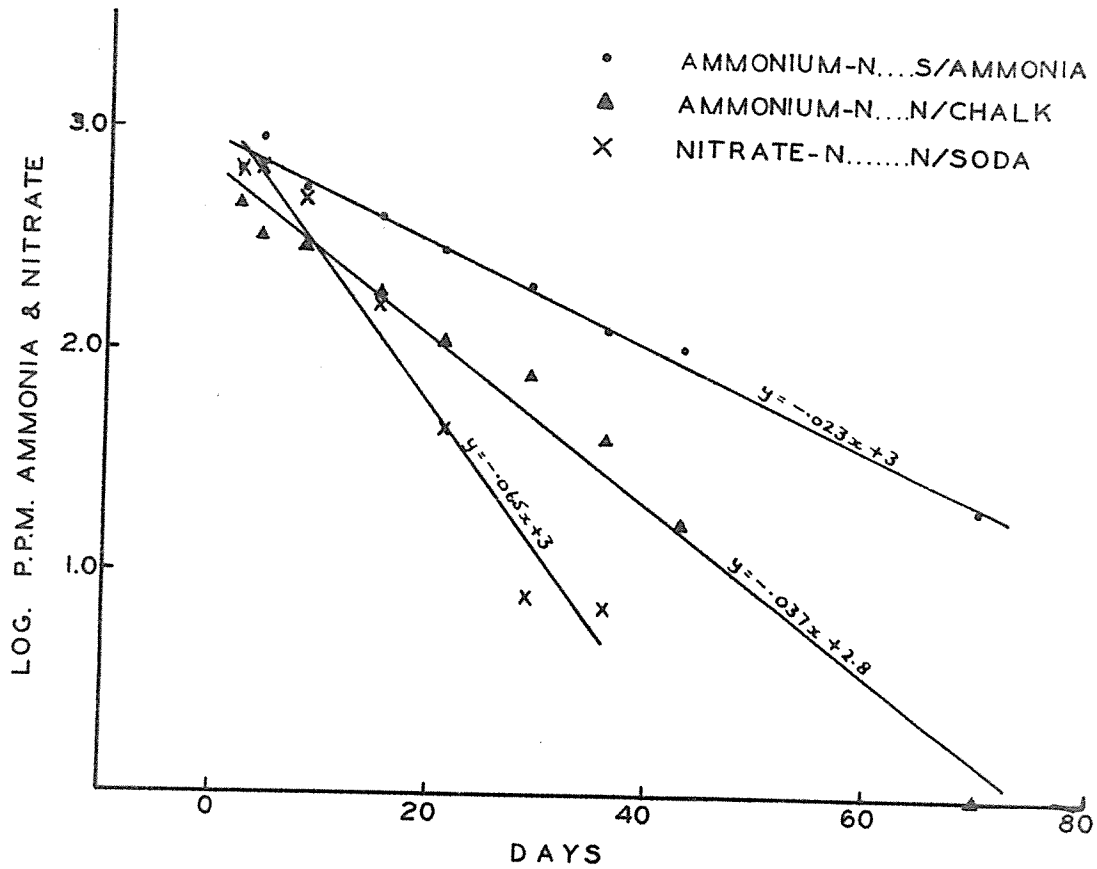


Fig. VII. The relationship between soil ammonium- and nitrate-nitrogen and time following the addition of nitrogenous fertilizers.

This showed that the amount of ammonia present in the top one-inch of soil after the application of sulphate of ammonia was inversely proportional to the time elapsed after application. It also showed that at any time the rate of disappearance of the added ammonia from the surface one-inch of soil was proportional to the amount present. The regression line is given by the equation $y = -.023x + 2.94$

where, $y = \log.$ ammonia value

and $x =$ time after application in days.

TABLE XIII

Regression of log. ammonia on days after application

Nitro-chalk

Source	SS	d.f.	M.S.	F	5%	1%	Result
Due to regression	5.4305	1	5.4305	343.70	5.59	12.25	H.S.
Error	0.1105	7	0.0158				
Total	5.5410	8					

The regression line is given by the equation

$$y = -.037x + 2.79$$

where, $y = \log.$ ammonia values

and $x =$ time after application in days

This showed likewise that the amount of ammonia present in the top one-inch of bare soil after the application of nitro-chalk was inversely proportional to the time elapsed after application. It also showed that the rate of disappearance of the added ammonia from the surface one-inch of soil at any time, was proportional to the

amount present.

In addition there was a highly significant difference between the slopes of the two lines, as is shown in Table XIV.

TABLE XIV

Comparison of Regressions, log. ammonia on days after application for sulphate of ammonia and nitro-chalk.

Source	SS	d. f.	M. S.	F	5%	1%	Result
Diffs. between Regn.	0.4070	1	0.4070	40.82	4.60	8.86	H.S.
Error	0.1396	14	0.0099				
Dev. Av. Regression	0.5466	15					

This shows that the ammonia supplied in nitro-chalk disappeared from the surface one-inch of the soil at a rate faster than that supplied in sulphate of ammonia. This is to be expected since earlier it was found (Tables XII and XIII), that the rate of disappearance of added ammonia was proportional to the amount present.

An investigation of the ammonia levels in successive one-inch horizons, to a depth of 6 inches, on the 43rd day after application showed the values given in Table XV for treatment B minus control.

TABLE XV

Mean Ammonia Values in Successive Horizons
Sulphate of Ammonia 43rd day

HORIZON	AMMONIA P.P.M.
0" - 1"	111.0
1" - 2"	149.1
2" - 3"	106.5
3" - 4"	49.3
4" - 5"	20.3
5" - 6"	4.5

The comparatively low figure of 110.0 parts per million for the 0- to 1-inch horizon was no doubt due to loss of ammonia by nitrification and perhaps through uptake by weed seedlings appearing at the 43rd day. However, it is interesting to note that of the total ammonia in the top 6 inches, 59 per cent was present in the top 2 inches, 84 per cent in the top 3 inches, and 95 per cent in the top 4 inches. Thus there appeared to be little downward movement of added ammonia beyond 4 inches under the conditions of the experiment.

NITRATE

The means of the nitrate figures for the treatments and for the control at each sampling are given in Table XVI and shown graphically in Figure VI.

TABLE XVI
MEAN NITRATE-NITROGEN (P.P.M.)

DAYS	T R E A T M E N T			
	A	B	C	D
2	18	22	615	317
4	17	30	658	348
8	16	26	484	272
15	10	13	175	94
22	7	14	53	34
29	2	4	10	9
36	0	5	7	9
43	0	22	-	16
71	2	24	-	4

The figures for treatment C, nitrate of soda, show an initial increase followed by a sharp decrease, the rate of which gradually falls until, on the 36th day, the value approximates to that of the control.

The nitrate figures for treatment D, nitro-chalk, also show an initial increase on the 4th day, followed by a rapid, though decreasing rate of disappearance with time. A slight increase occurred on the 43rd day, but the mean figure for the 71st day is little different from that of the control.

The nitrate figures for the sulphate of ammonia treatment do not rise to more than 13 p.p.m. above those of the control until the 43rd and 71st days, when conditions apparently favoured nitrate accumulation.

The analyses of the results for the Latin Square method using Snedecor's F test (Snedecor, 1940) and

Fisher's t test (Fisher, 1948) appear in Table XVII, where the following symbols are used.

N.S. = not significant at 5% level of probability.

S = significant at 5% level but not at 1% level.

H.S. = significant at 1% level of probability.

($\bar{d} = .05$) = value required for difference between means at 5% level.

($\bar{d} = .01$) = value required for difference between means at 1% level.

A > B = the mean of A is greater than that of B at 5% level.

A >> B = the mean of A is greater than that of B at 1% level.

TABLE XVII
ANALYSIS OF NITRATE RESULTS

DAY	ANALYSIS OF VARIANCE			DIFFS. BETWEEN MEANS t TEST			
	F	RESULT	Error d.f.	($\bar{d} = .05$)	Result	($\bar{d} = .01$)	Result
2	113.67	H.S.	6	82.26	C>D>(A,B)	115.33	C>>D>>(A,B)
4	111.43	H.S.	6	88.86	C>D>(A,B)	124.58	C>>D>>(A,B)
8	120.36	H.S.	6	62.54	C>D>(A,B)	87.68	C>>D>>(A,B)
15	202.70	H.S.	6	16.95	C>D>(A,B)	23.76	C>>D>>(A,B)
22	22.76	H.S.	6	13.08	C>D>(A,B)	17.93	C>>D>>(A,B)
29	5.55	S	6	5.38	(C,D)>A	-	-
36	20.40	H.S.	6	2.44	D>B>A	3.92	D>>B>>A;C>>A
43	38.84	H.S.	6	6.83	(B,D)>A	9.81	(B,D)>>A
71	116.57	H.S.	6	3.52	B>(A,D)	5.12	B>>(A;D)

This shows that,

1. Nitrate which accumulated from the application of nitrate of soda (treatment C), persisted until the 22nd day after application in a significantly greater amount than that from either nitro-chalk or sulphate of ammonia.
2. Nitrate from nitro-chalk persisted until the 36th

day in an amount that was significantly greater than that from the sulphate of ammonia treatment or from the no-nitrogen treatment.

3. Nitrate in the sulphate of ammonia treated plots accumulated to the extent that it was significantly greater in amount than that in the no-nitrogen treatment on the 43rd and greater than either the no-nitrogen treatment or nitro-chalk treatment on the 71st day after application.

A highly significant regression of the logarithm of the mean nitrate values from the nitrate of soda treatment on time was found, as is shown in Table XVIII and Figure VII.

TABLE XVIII

Regression of log. nitrate on days after application

Nitrate of Soda							
Source	SS	d.f.	M.S.	F	5%	1%	Result
Due to Regression	4.2562	1	4.2562	140	6.61	16.26	H.S.
Error	0.1520	5	0.0304				
Total	4.4082	6					

The regression equation is, $y = -.065x + 3.057$

where, y is the logarithm of the ammonia value

and x is the time after application in days

From this it may be interpreted that:

1. The amount of nitrate-nitrogen present in the top one inch of soil after the application of nitrate of soda was inversely proportional to the time elapsed after

application.

2. The rate of disappearance of the added nitrate from the surface one inch of soil, at any time, was proportional to the amount present.

It was also found that there was a highly significant difference between the slopes of the ammonia regression on time, from treatment B and the nitrate regression on time from treatment C. This is shown in Table XIX.

TABLE XIX

Comparison of Regressions, Treatment B log. ammonia on time with Treatment C log. nitrate on time.

Source	SS	d. f.	M. S.	F	5%	1%	Result
Diffs. between Regn.	1.4339	1	1.4339	94.95	4.75	9.33	H.S.
Error	0.1811	12	0.0151				
Dev. Av. Re- gression	1.6150	13					

The interpretation is that the nitrogen supplied as nitrate in nitrate of soda disappeared from the surface one inch of soil at a rate faster than an equivalent amount of nitrogen supplied as ammonia in sulphate of ammonia, under the conditions of the experiment.

SOIL pH

Mean pH values for each treatment at each sampling are given in Table XX and are shown graphically as com-

pared with a straight-line representation of the control in Figure VIII.

TABLE XX
MEAN SOIL pH VALUES

DAYS	T R E A T M E N T S			
	A	B	C	D
2	4.71	4.60	4.70	6.46
4	5.01	4.77	4.86	6.72
8	5.04	4.78	4.92	6.49
15	4.89	4.78	5.06	6.34
22	5.19	5.18	5.56	6.37
29	4.94	5.12	5.47	5.89
36	5.38	5.37	5.72	5.80
43	5.18	4.85	-	5.51
71	5.56	4.60	-	6.00

The curve for the sulphate of ammonia treatment shows that there is a gradual increase in acidity up to the 8th day and then a decrease in acidity so that on the 29th day the sulphate of ammonia treated soil was less acid than the no-nitrogen treatment (pH 5.12 compared with pH 4.94). Thenceforward, the curve shows an increasing acidity and at the 71st day the mean pH for the sulphate of ammonia treatment was 4.60 compared with 5.56 for the control.

The nitrate of soda curve shows a slight initial increase in acidity for the 4th and 8th days, and then a decrease in acidity up to the 29th day. This was followed by a slight fall in pH to 5.72 on the 36th day compared with 5.38 for the control.

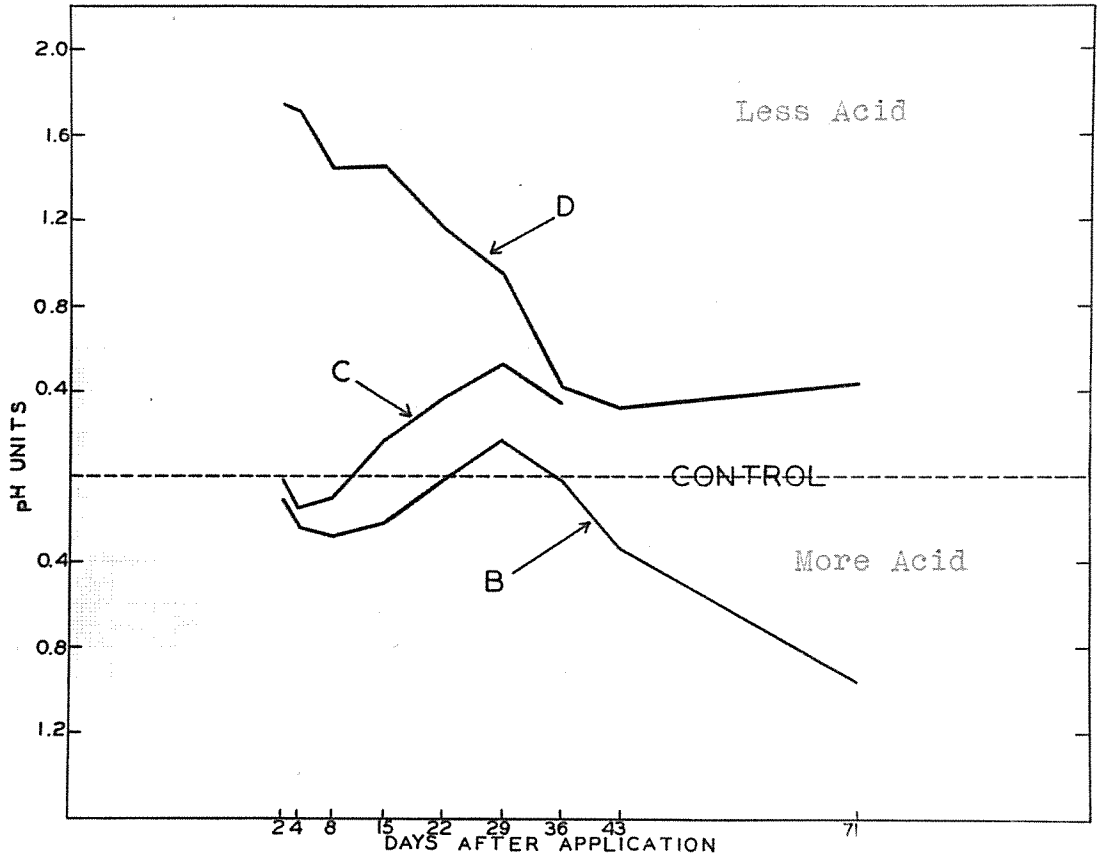


Fig. VIII. The comparative fluctuations in soil pH following the addition of nitrogenous fertilizers. The symbols used are as follows: B = sulphate of ammonia, C = nitrate of soda and D = nitro-chalk.

For nitro-chalk, the curve started at a near-neutral pH of 6.46 on the 2nd day and showed a gradual slow increase in acidity to the 43rd day, when it stood at pH 5.51 compared with 5.18 for the no-nitrogen treatments. Then this was followed by a slight rise on the 71st day to pH 6.00 compared with 5.56 for the control.

SOIL TEMPERATURE

Soil temperature readings were made at about 10 a.m. on the day of sampling at a depth of $\frac{1}{2}$ -inch and are recorded as means for all treatments in Table XXI.

TABLE XXI

MEAN SOIL TEMPERATURE °C

DAY	TEMPERATURE
2	13.5
7	13.5
8	12.5
15	12.5
22	11.0
29	11.0
36	11.5
43	9.5
71	1.0

The figures show that soil temperature fell gradually from 13.5 at the start of the experiment to 1.0°C on the 71st day after application.

SOIL MOISTURE

Soil moisture figures are recorded in Table XXII.

TABLE XXII
MEAN SOIL MOISTURE PERCENTAGE OF DRY SOIL

DAY	T R E A T M E N T			
	A	B	C	D
2	32.5	32.5	32.0	32.5
4	30.75	31.25	32.0	31.75
8	31.0	30.5	31.75	33.5
15	36.0	35.0	36.6	35.85
22	36.7	36.0	37.0	36.0
29	40.9	40.9	41.1	41.1
36	40.9	40.2	41.1	41.4
43	36.48	36.35	-	36.6
71	37.47	40.86	-	39.98

The mean soil moisture figures for all treatments showed the same trends, decreasing to a minimum at the 4th or 8th day and then increasing to peaks on the 29th or 36th days and then falling slightly to the 43rd and 71st days.

RAINFALL RECORDS

Monthly rainfall records are summarised in Table XXIII and are shown graphically in Figure VI.

TABLE XXIII
MONTHLY RAINFALL 3 MONTHS 1952

MONTH	INCHES RAIN
May	2.81
June	7.76
July	1.86

The fertilizers were applied on May 5th, following which date a total of 0.13 inches rain fell in the next

10 days. From then to the 15th day (May 20th) 0.69 inches fell, and in the next four successive weeks 1.45, 2.15, 3.27 and 0.36 inches of rainfall respectively occurred. From the 43rd to the 71st day (June 17th to July 15th) a further 3.39 inches of rain fell, but the last week of that period was completely rainless.

EXPERIMENT 2.

AMMONIA

The mean ammonia values for the two treatments at both depths sampled are presented in Table XXIV and shown graphically in Figure IX.

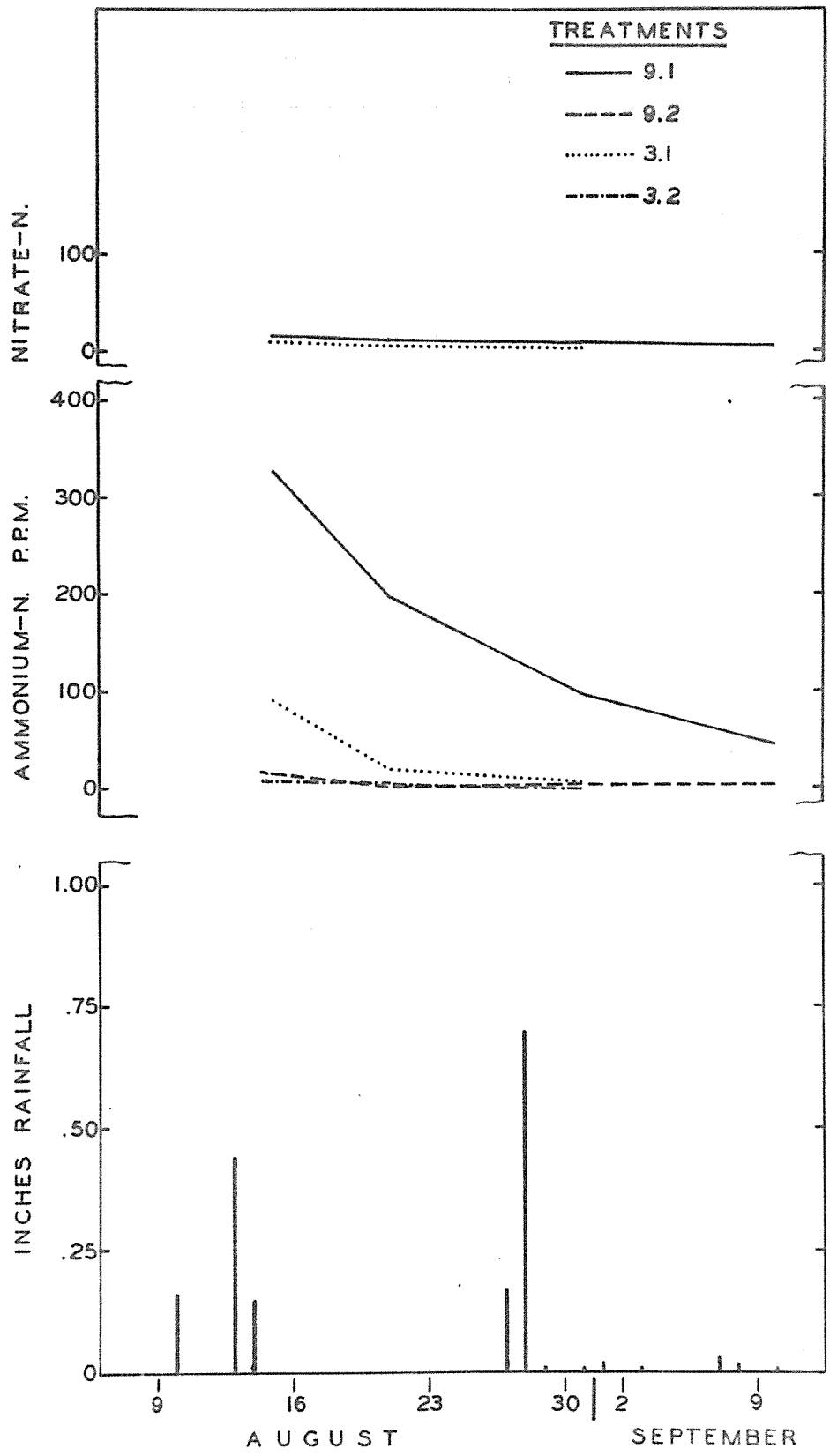
TABLE XXIV
MEAN AMMONIUM-NITROGEN

DAYS	T R E A T M E N T			
	3 cwt.		9 cwt.	
	0" - 3"	3" - 6"	0" - 3"	3" - 6"
4	92	11	328	12
10	22	5	197	5
20	7	4	100	6
30	-	-	45	4

In the 0- to 3-inch horizon, the figures for the 3 cwt. treatment show a sharp decrease from the 4th to the 10th day, with a more gradual decrease to the 20th day. The figures for the 9 cwt. treatment also show the same trend, a sharp decrease from the 4th to the 10th day, a smaller decrease from the 10th to the 20th day and a more gradual decrease from the 20th to the 30th

Fig. IX. Soil ammonium- and nitrate-nitrogen following the addition of sulphate of ammonia to grassland. The following symbols are used: 9.1 = 9 cwt. per acre at 0- to 3-inch depth, 9.2 = 9 cwt. per acre at 3- to 6-inch depth, 3.1 = 3 cwt. per acre at 0- to 3- inch depth, and 3.2 = 3 cwt. per acre at 3- to 6- inch depth.

Note. Only the values for the surface horizon of each treatment are shown in the nitrate graph to avoid confusion due to the small variations between treatments.



day.

In the 3- to 6- inch horizon, the means for both treatments are closely similar, showing 11 p.p.m. on the 4th day for the 3 cwt. treatment decreasing to 4 on the 20th, while that for the 9 cwt. treatment decreases from 12 p.p.m. on the 4th day to 6 on the 20th and to 4 p.p.m. on the 30th day.

The analysis of the ammonia figures for a randomised block design is given in Table XXV. The methods of analysis used are Snedecor's F test and Fisher's t test to determine overall significant differences between treatments, depths and interaction, and differences between individual means respectively. The following symbols are used:

N.S. = not significant at 5% level of probability

S = significant at 5% level but not at 1% level

H.S. = significant at 1% level of probability

($d = .05$) = value required for difference between means at 5% level

($d = .01$) = value required for difference between means at 1% level

$A_1 > B_1$ = the mean of A at the 0- to 3- inch depth is greater than that of B at the 0- to 3- inch depth at the 5% level of probability.

$A_2 > B_2$ = the mean of A at the 3- to 6- inch depth is greater than B at the 3- to 6- inch depth, at the 5% level of probability.

A = 3 cwt. treatment

B = 9 cwt. treatment

$A_1 \gg B_1$ = the mean of A at the 0- to 3- inch depth is greater than that of B at the 0- to 3-inch depth at the 1% level of probability.

The Error number degrees of freedom are 9 for the 4th, 10th and 20th days and 7 for the analyses of the 30th day.

TABLE XXV
ANALYSIS OF AMMONIA RESULTS

DAY	TREATMENTS		DEPTHS		INTERACTION		DIFFS. BETWEEN MEANS		
	F	Result	F	Result	F	Result	(d=.05)	(d=.01)	Result
4	48.96	H.S.	13.14	H.S.	47.93	HS.	53.99	77.58	$B_1 \gg A_1 \gg A_2 B_2$
10	97.00	H.S.	139.09	H.S.	97.00	HS.	28.39	40.79	$B_1 \gg (A_1 A_2 B_2)$
20	207.74	H.S.	216.53	H.S.	190.61	HS.	10.54	15.15	$B_1 \gg (A_1 A_2 B_2)$
30	-	-	110.48	H.S.	-	-	9.23	13.65	$B_1 \gg B_2$

It may be concluded that,

1. Throughout the course of the experiment, the mean ammonia level in the surface horizon of the 9 cwt. treated plots was significantly greater than that in its respective lower horizon and greater than the means in both the upper and lower horizons of the 3 cwt. treatment.
2. On the 4th day, the mean ammonia figure for the upper horizon of the 3 cwt. treatment was significantly greater than the means of the lower horizon of either treatment. From the 10th day, there was no significant difference between the means of the upper and lower horizons of the 3 cwt.

treatment and the lower horizon of the 9 cwt. treatment.

3. The means for the lower horizon of the 9 cwt. treatment were never significantly different from the means for the lower horizon of the 3 cwt. treatment.

Unfortunately the ammonia values decreased at a faster rate than expected and it was not practicable to make observations at closer intervals than was done.

NITRATE

The mean nitrate values for both treatments are given in Table XXVI and are shown graphically in Figure IX.

TABLE XXVI

MEAN NITRATE-NITROGEN

DAYS	T R E A T M E N T S			
	3 cwt.		9 cwt.	
	0" - 3"	3" - 6"	0" - 3"	3" - 6"
4	10	8	12	4
10	6	5	8	4
20	4	3	7	4
30	-	-	6	4

In the 0- to 3-inch horizon, the figures for the 3 cwt. treatment show a gradual decrease from 10 p.p.m. on the 4th day, to 6 on the 10th and 4 on the 20th. A similar trend is shown in the mean figures for the 9 cwt. treatment, decreasing from 12 p.p.m. on the 4th day to 6 on the 30th.

At the 3- to 6-inch level, the mean figures for the 3 cwt. treatment decrease from 8 p.p.m. on the 4th day to 5 on the 10th and 3 on the 20th. The figures for the 9 cwt. treatment show no variation and remain at 4 p.p.m. throughout the course of the investigation.

The analysis of the mean nitrate figures is given in Table XXVII where the symbols used are those that have been explained previously. The Error degrees of freedom are 9 for the analyses for the 4th, 10th and 20th days and 7 for those of the 30th day.

TABLE XXVII
ANALYSIS OF NITRATE RESULTS

DAY	TREATMENTS		DEPTHS		INTERACTION		DIFFS. BETWEEN MEANS		
	F	Result	F	Result	F	Result	(d=.05)	(d=.01)	Result
4	0.03	N.S.	3.13	N.S.	1.16	N.S.	-	-	-
10	0.30	N.S.	7.50	S	2.70	N.S.	2.02	-	$B_1 > (A_2, B_2)$
20	2.15	N.S.	2.15	N.S.	3.49	N.S.	-	-	-
30	-	-	3.27	N.S.	-	-	-	-	-

The interpretation is that,

1. Throughout the period of the investigation, there was no significant difference in the mean nitrate level, at either depth sampled, between the 3 cwt.-treated and the 9 cwt.-treated plots.
2. On only one occasion was there a significant difference between depths. This occurred on the 10th day when

the mean nitrate value of the upper horizon of the 9 cwt. treatment was significantly higher than the lower horizons of either of the treatments. Thus the application of sulphate of ammonia at the rate of 9 cwt. per acre to the surface of a grassland soil caused an accumulation of nitrate nitrogen in the 0- to 3-inch horizons, that was significantly greater than the nitrate status in the upper horizon of plots that had received sulphate of ammonia at the rate of 3 cwt. per acre.

SOIL TEMPERATURE

Overall mean soil temperatures for each sampling date at $1\frac{1}{2}$ -inch and $4\frac{1}{2}$ -inch depths are given in Table XXVIII.

TABLE XXVIII
MEAN SOIL TEMPERATURE °C

DAYS	T E M P E R A T U R E	
	$1\frac{1}{2}$ ins.	$4\frac{1}{2}$ ins.
4	10.5	10.0
10	12.0	11.5
20	12.0	11.5
30	12.0	11.5

For the surface horizon the soil temperature showed an initial increase from 10.5°C on the 4th day to 12.0°C on the 10th and remained at that value on the 20th and 30th days. In the lower horizon the mean soil temperature increased from 10°C on the 4th day to 11.5°C on the 10th and remained at that value on the 20th and 30th days.

SOIL MOISTURE

Mean soil moisture figures for each treatment and depth at each sampling date are given in Table XXIX.

TABLE XXIX

MEAN SOIL MOISTURE PER CENT OF DRY SOIL

DAYS	T R E A T M E N T			
	3 cwt.		9 cwt.	
	0" - 3"	3" - 6"	0" - 3"	3" - 6"
4	41.1	39.6	40.9	39.4
10	36.5	35.0	37.6	36.1
20	39.9	37.0	39.8	36.7
30	-	-	35.7	34.3

The mean soil moisture values throughout the period of the experiment were as follows:

3 cwt. treatment, 39.2 per cent for the 0- to 3- inch horizon and 37.2 per cent for the 3- to 6- inch horizon.

9 cwt. treatment, 38.5 per cent for the 0- to 3- inch horizon and 36.6 per cent for the 3- to 6- inch horizon.

RAINFALL

During the period August 11th to September 10th when observations were made, 1.57 inches of rainfall were recorded. Of this total, 0.44 inches fell on August 13th and a further 0.7 inches on August 28th. From August 29th until the end of the experiment only 0.11 inches were

recorded. Thus between the date of application of the fertilizer and the first sampling on August 15th, 0.59 inches of rain fell. Between the 4th and 10th days no rain fell. From the 10th to 20th, 0.89 inches were recorded and between the 20th and 30th days, 0.09 inches fell.

CHAPTER V

DISCUSSION OF RESULTS

The comparative rates of disappearance of the three nitrogen fertilizers applied to a bare soil surface are of interest. The free movement of nitrate in the soil is well known and therefore percolating water results in the rapid leaching of nitrate. In the present study the nitrate supplied in nitrate of soda had disappeared completely from the soil surface within five weeks of application. On the other hand, ammonia disappeared at a significantly slower rate from the soil surface. Even ten weeks after the application of sulphate of ammonia at a nitrogen rate comparable to that of nitrate of soda the soil ammonia status was still significantly higher than that to which ^{no} the nitrogen fertilizer had been added.

The influence of the fertilizers on soil pH was as expected. In addition to the direct effects of the added ions on pH, it should be realised that there might have been an indirect effect such as stimulation or inhibition of soil micro-organisms with consequent increases or decreases in the rate of ammonification or nitrification of the native soil nitrogen.

The finding that there is a rapid disappearance of nitrogen from the sulphate of ammonia applied to grassland supports the work of Richardson (1933, 1935, 1938). The mineral nitrogen was not leached as analyses of the lower soil layer failed to show any significant accumulation of

ammonia in nitrate during the course of the experiment. Thus the applied nitrogen must have been either rapidly taken up by the herbage, converted into microbial tissue and perhaps excreted as organic nitrogen compounds, or lost by volatilisation or denitrification into the atmosphere. The almost immediate response of the grass as indicated by enhanced growth and deep green colour suggested that a large amount of the applied nitrogen was being taken up. Presumably, as nitrate accumulation was not apparent, this uptake was in the form of ammonia rather than through nitrification to nitrate. Martin and Chapman (1951) reported losses of ammonia by volatilisation from a number of nitrogenous fertilizers when applied to the soil surface. Consequently losses of this form may have been one of the factors accounting for the rapid disappearance of the nitrogen applied in the present investigation.

Merrill and Springer (1945) assumed that in grass orchards, where there is competition between the grass cover and the trees for applied nutrients, band application around the drip-area of the trees would result in a larger proportion of the applied nutrients penetrating to the tree roots.

However, the present study has indicated that the placement of sulphate of ammonia in concentrated bands in grassland results in no significant increase in the ammonia or nitrate status of the sub-surface soil layers

compared with the same fertilizer broadcast over the whole area at the same total rate per acre.

Studies have indicated that the feeder roots of fruit trees in grass orchards often occur within the surface three-inches of the soil (May, 1950 and others). Thus although there is little vertical movement of sulphate of ammonia, the trees will benefit in all probability from surface applications of sulphate of ammonia, provided this is applied at a rate sufficient to maintain a relatively high ammonia status in the soil surface layers. The addition of nitrogen fertilizers to grass orchards will in turn stimulate the growth of the grass and may therefore have an indirectly beneficial effect on tree nutrition.

An alternative to the application of sulphate of ammonia to grass orchards may be the addition of nitrate of soda or some other nitrate-containing fertilizer. In this case, penetration of the applied nitrogen may be greater than with sulphate of ammonia, particularly under high rainfall conditions, and may therefore result in a greater proportion of the applied nitrogen penetrating to the lower tree roots. This point, however, was not investigated in the present study.

CHAPTER VI

SUMMARY

A brief review has been made of literature relevant to the study of the movement and disappearance of mineral nitrogen in soil following the application of nitrogen fertilizers. Various publications dealing with the effects of nitrogen fertilizers on the base status and on soil pH have also been reviewed.

It has been found that nitrate disappeared rapidly from the surface soil layers following the application of nitrate of soda and nitro-chalk to the soil surface. Ammonia from sulphate of ammonia and nitro-chalk tended to persist in the surface soil layers longer than nitrate. Little penetration of ammonia from sulphate of ammonia to below four inches occurred.

A comparison of surface applications of sulphate of ammonia to grassland at the rates of 3 and 9 cwts. per acre has showed that there was no significant difference in the amounts of ammonia which penetrated to the sub-surface soil layers. Nitrate did not accumulate to any significant extent following the addition of sulphate of ammonia to grassland and it is concluded that nitrogen was taken up by the grass plants as ammonia without nitrification.

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A C K N O W L E D G E M E N T S

I wish to acknowledge the assistance given by the following who have helped at some stages during the preparation of this thesis.

Mr. C.V.Fife, my supervisor, who suggested the topics for study and gave advice and helpful discussion during the planning of the experiments.

Mr. K.C. Hockey for permission to use the Batchelar orchard area for the first part of the experiment.

Mr. A. Glenday, Biometrician, Grasslands Division, for statistical advice and assistance during the planning of the experiments and the interpretation of the results.

Miss Mary G. Campbell and her library staff for their unfailing help at all times.

Miss E.S. Francis for typing the manuscript in its final form.

Miss Betty Gust and Dr. W.A. McGillivray for the photographic work.

APPENDIX I

AMMONIUM-NITROGEN

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	AMMONIUM-N P.P.M.
February 23	Clean-cultivation	5	1	0 - 2	12.0
			2	0 - 2	16.0
	Grassland	5	1	0 - 2	9.5
			2	0 - 2	7.6
February 25	Clean-cultivation	2	1	0 - 2	20.0
			2	0 - 2	11.0
			3	0 - 2	18.0
			4	0 - 2	11.0
		5	1	0 - 2	15.0
			2	0 - 2	10.0
			3	0 - 2	14.0
			4	0 - 2	10.0
		6	1	0 - 2	10.0
			2	0 - 2	20.0
			3	0 - 2	22.0
			4	0 - 2	20.0
	Grassland	2	1	0 - 2	18.0
			2	0 - 2	12.0
			3	0 - 2	12.0
			4	0 - 2	12.0
		5	1	0 - 2	13.0
			2	0 - 2	15.0
			3	0 - 2	7.0
			4	0 - 2	11.0
		6	1	0 - 2	15.0
			2	0 - 2	14.0
			3	0 - 2	12.0
			4	0 - 2	22.0
March 6	Clean-cultivation	1	1	0 - 2	18.0
		2	1	0 - 2	16.0
		3	1	0 - 2	15.0
		4	1	0 - 2	20.0
		5	1	0 - 2	13.0
		6	1	0 - 2	20.0
		7	1	0 - 2	10.0
		8	1	0 - 2	17.0
	Grassland	1	1	0 - 2	9.0
		2	1	0 - 2	20.0
		3	1	0 - 2	4.0
		4	1	0 - 2	4.0
		5	1	0 - 2	12.0
		6	1	0 - 2	12.0
		7	1	0 - 2	9.0
		8	1	0 - 2	16.0

APPENDIX I (continued)

AMMONIUM-NITROGEN (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	AMMONIUM-N P.P.M.
March 28	Clean-cultivation	3	1	0 - 2	13.0
		3	1	2 - 4	4.0
		6	1	0 - 2	10.0
		6	1	2 - 4	3.0
		7	1	0 - 2	9.0
		7	1	2 - 4	3.0
		8	1	0 - 2	7.0
		8	1	2 - 4	0.0
	Grassland	3	1	0 - 2	2.0
		3	1	2 - 4	0.0
		6	1	0 - 2	4.0
		6	1	2 - 4	6.0
		7	1	0 - 2	10.0
		7	1	2 - 4	4.0
8		1	0 - 2	1.0	
8		1	2 - 4	1.0	
April 18	Clean-cultivation	3	1	0 - 2	7.0
		3	1	2 - 4	3.0
		6	1	0 - 2	5.0
		6	1	2 - 4	11.0
		7	1	0 - 2	5.0
		7	1	2 - 4	6.0
		8	1	0 - 2	8.0
		8	1	2 - 4	2.0
	Grassland	3	1	0 - 2	8.0
		3	1	2 - 4	9.0
		6	1	0 - 2	12.0
		6	1	2 - 4	3.0
		7	1	0 - 2	14.0
		7	1	2 - 4	6.0
8		1	0 - 2	16.0	
8		1	2 - 4	2.0	
May 16	Clean-cultivation	3	1	0 - 2	7.8
		3	1	2 - 4	7.5
		6	1	0 - 2	4.5
		6	1	2 - 4	2.9
		7	1	0 - 2	6.0
		7	1	2 - 4	3.0
		8	1	0 - 2	9.8
		8	1	2 - 4	4.4

APPENDIX I (continued)

AMMONIUM NITROGEN (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE	DEPTH OF SAMPLING	AMMONIUM-N P. P. M.
May 16	Grassland	3	1	0 - 2	6.4
		3	1	2 - 4	2.2
		6	1	0 - 2	12.4
		6	1	2 - 4	7.5
		7	1	0 - 2	6.4
		7	1	2 - 4	10.2
		8	1	0 - 2	8.7
		8	1	2 - 4	4.3
		8	1	2 - 4	
June 13	Clean-cultivation	3	1	0 - 2	Trace
		3	1	2 - 4	6.0
		6	1	0 - 2	2.5
		6	1	2 - 4	8.7
		7	1	0 - 2	1.6
		7	1	2 - 4	5.3
		8	1	0 - 2	Nil
		8	1	2 - 4	3.0
	Grassland	3	1	0 - 2	Nil
		3	1	2 - 4	2.3
		6	1	0 - 2	Trace
		6	1	2 - 4	2.0
		7	1	0 - 2	Trace
		7	1	2 - 4	4.0
		8	1	0 - 2	Nil
8	1	2 - 4	Trace		

APPENDIX II

NITRATE-NITROGEN

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	NITRATE-N P.P.M.
February 23	Clean-cultivation	5	1	0 - 2	124.0
			2	0 - 2	145.0
	Grassland	5	1	0 - 2	20.6
			2	0 - 2	8.3
February 25	Clean-cultivation	2	1	0 - 2	117.0
			2	0 - 2	106.0
			3	0 - 2	100.0
			4	0 - 2	96.0
		5	1	0 - 2	105.0
			2	0 - 2	105.0
			3	0 - 2	103.0
			4	0 - 2	105.0
		6	1	0 - 2	114.0
			2	0 - 2	117.0
			3	0 - 2	136.0
			4	0 - 2	134.0
February 25	Grassland	2	1	0 - 2	5.0
			2	0 - 2	3.0
			3	0 - 2	3.0
			4	0 - 2	13.0
		5	1	0 - 2	19.0
			2	0 - 2	18.0
			3	0 - 2	10.0
			4	0 - 2	15.0
		6	1	0 - 2	9.0
			2	0 - 2	10.0
			3	0 - 2	6.0
			4	0 - 2	17.0
March 6	Clean-cultivation	1	1	0 - 2	184.0
		2	1	0 - 2	149.0
		3	1	0 - 2	183.0
		4	1	0 - 2	164.0
		5	1	0 - 2	176.0
		6	1	0 - 2	192.0
		7	1	0 - 2	188.0
		8	1	0 - 2	171.0

APPENDIX II (continued)

NITRATE-NITROGEN (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	NITRATE-N P. P. M.
March 6	Grassland	1	1	0 - 2	2.0
		2	1	0 - 2	5.0
		3	1	0 - 2	5.0
		4	1	0 - 2	5.0
		5	1	0 - 2	16.0
		6	1	0 - 2	15.0
		7	1	0 - 2	12.0
		8	1	0 - 2	53.0*
March 28	Clean-cultivation	3	1	0 - 2	152.0
		3	1	2 - 4	74.0
		6	1	0 - 2	123.0
		6	1	2 - 4	65.0
		7	1	0 - 2	96.0
		7	1	2 - 4	60.0
		8	1	0 - 2	97.0
		8	1	2 - 4	64.0
March 28	Grassland	3	1	0 - 2	9.0
		3	1	2 - 4	4.0
		6	1	0 - 2	7.0
		6	1	2 - 4	11.0
		7	1	0 - 2	16.0
		7	1	2 - 4	9.0
		8	1	0 - 2	12.0
		8	1	2 - 4	7.0
April 18	Clean-cultivation	3	1	0 - 2	127.0
		3	1	2 - 4	54.0
		6	1	0 - 2	143.0
		6	1	2 - 4	50.0
		7	1	0 - 2	118.0
		7	1	2 - 4	56.0
		8	1	0 - 2	147.0
		8	1	2 - 4	50.0
April 18	Grassland	3	1	0 - 2	3.0
		3	1	2 - 4	0.0
		6	1	0 - 2	6.0
		6	1	2 - 4	2.0
		7	1	0 - 2	12.0
		7	1	2 - 4	7.0
		8	1	0 - 2	16.0
		8	1	2 - 4	4.0

APPENDIX II (continued)

NITRATE-NITROGEN (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	NITRATE-N P.P.M.
May 16	Clean-cultivation	3	1	0 - 2	37.5
		3	1	2 - 4	32.1
		6	1	0 - 2	35.5
		6	1	2 - 4	30.9
		7	1	0 - 2	45.9
		7	1	2 - 4	41.7
		8	1	0 - 2	24.9
		8	1	2 - 4	27.7
May 16	Grassland	3	1	0 - 2	12.1
		3	1	2 - 4	10.7
		6	1	0 - 2	17.4
		6	1	2 - 4	12.7
		7	1	0 - 2	16.9
		7	1	2 - 4	18.7
		8	1	0 - 2	14.3
		8	1	2 - 4	9.4
June 13	Clean-cultivation	3	1	0 - 2	Trace
		3	1	2 - 4	4.6
		6	1	0 - 2	Nil
		6	1	2 - 4	6.3
		7	1	0 - 2	Nil
		7	1	2 - 4	3.5
		8	1	0 - 2	Trace
		8	1	2 - 4	3.9
June 13	Grassland	3	1	0 - 2	2.0
		3	1	2 - 4	3.0
		6	1	0 - 2	1.8
		6	1	2 - 4	2.5
		7	1	0 - 2	Trace
		7	1	2 - 4	2.0
		8	1	0 - 2	1.8
		8	1	2 - 4	2.9

* The comparatively high figure of 53.0 p.p.m. of ammonium-nitrogen on March 6th was probably due to contamination during sampling. This figure was disregarded in all calculations of means, analysis of variance etc.

APPENDIX III

SOIL pH

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	SOIL pH
March 28	Clean-cultivation	3	1	0 - 2	5.0
		3	1	2 - 4	5.1
		6	1	0 - 2	5.1
		6	1	2 - 4	5.1
		7	1	0 - 2	5.4
		7	1	2 - 4	5.6
		8	1	0 - 2	5.5
		8	1	2 - 4	5.6
	Grassland	3	1	0 - 2	5.8
		3	1	2 - 4	5.6
		6	1	0 - 2	6.0
		6	1	2 - 4	5.9
		7	1	0 - 2	6.0
		7	1	2 - 4	5.8
8		1	0 - 2	6.1	
8		1	2 - 4	6.2	
April 18	Clean-cultivation	3	1	0 - 2	5.14
		3	1	2 - 4	5.50
		6	1	0 - 2	5.36
		6	1	2 - 4	5.60
		7	1	0 - 2	5.35
		7	1	2 - 4	5.62
		8	1	0 - 2	5.03
		8	1	2 - 4	5.14
	Grassland	3	1	0 - 2	6.08
		3	1	2 - 4	6.23
		6	1	0 - 2	6.21
		6	1	2 - 4	6.08
		7	1	0 - 2	5.95
		7	1	2 - 4	6.05
8		1	0 - 2	5.94	
8		1	2 - 4	5.97	
May 16	Clean-cultivation	3	1	0 - 2	5.35
		3	1	2 - 4	5.38
		6	1	0 - 2	5.17
		6	1	2 - 4	5.06
		7	1	0 - 2	5.57
		7	1	2 - 4	5.61
		8	1	0 - 2	5.78
		8	1	2 - 4	5.78

APPENDIX III (continued)

SOIL pH (Continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	SOIL pH
May 16	Grassland	3	1	0 - 2	5.76
		3	1	2 - 4	5.47
		6	1	0 - 2	5.95
		6	1	2 - 4	5.81
		7	1	0 - 2	5.93
		7	1	2 - 4	5.78
		8	1	0 - 2	6.05
		8	1	2 - 4	5.86
June 13	Clean-cultivation	3	1	0 - 2	6.02
		3	1	2 - 4	6.06
		6	1	0 - 2	6.04
		6	1	2 - 4	5.80
		7	1	0 - 2	6.35
		7	1	2 - 4	6.31
		8	1	0 - 2	6.26
		8	1	2 - 4	6.22
June 13	Grassland	3	1	0 - 2	6.08
		3	1	2 - 4	6.00
		6	1	0 - 2	6.30
		6	1	2 - 4	6.30
		7	1	0 - 2	6.40
		7	1	2 - 4	6.40
		8	1	0 - 2	6.22
		8	1	2 - 4	6.26

APPENDIX IV

SOIL MOISTURE
Percentage of Dry Soil

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	PERCENTAGE SOIL MOISTURE
February 23	Clean-cultivation	5	1	0 - 2	19.6
			2	0 - 2	28.2
	Grassland	5	1	0 - 2	29.9
			2	0 - 2	25.0
February 25	Clean-cultivation	2	1	0 - 2	30.0
			2	0 - 2	19.0
			3	0 - 2	22.0
			4	0 - 2	23.0
		5	1	0 - 2	22.0
			2	0 - 2	20.0
			3	0 - 2	22.0
			4	0 - 2	26.0
		6	1	0 - 2	22.0
			2	0 - 2	23.0
			3	0 - 2	23.0
			4	0 - 2	20.0
	Grassland	2	1	0 - 2	18.0
			2	0 - 2	19.0
			3	0 - 2	20.0
			4	0 - 2	20.0
		5	1	0 - 2	25.0
			2	0 - 2	28.0
			3	0 - 2	23.0
			4	0 - 2	21.0
6	1	0 - 2	22.0		
	2	0 - 2	20.0		
	3	0 - 2	19.0		
	4	0 - 2	23.0		
March 6	Clean-cultivation	1	1	0 - 2	24.0
		2	1	0 - 2	26.0
		3	1	0 - 2	25.0
		4	1	0 - 2	25.0
		5	1	0 - 2	25.0
		6	1	0 - 2	27.0
		7	1	0 - 2	25.0
		8	1	0 - 2	23.0

APPENDIX IV (continued)

SOIL MOISTURE (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	PERCENTAGE SOIL MOISTURE
March 6	Grassland	1	1	0 - 2	26.0
		2	1	0 - 2	20.0
		3	1	0 - 2	21.0
		4	1	0 - 2	21.0
		5	1	0 - 2	23.0
		6	1	0 - 2	22.0
		7	1	0 - 2	23.0
		8	1	0 - 2	22.0
March 28	Clean-cultivation	3	1	0 - 2	25.6
		3	1	2 - 4	23.0
		6	1	0 - 2	25.4
		6	1	2 - 4	23.0
		7	1	0 - 2	24.2
		7	1	2 - 4	23.6
		8	1	0 - 2	25.2
		8	1	2 - 4	22.6
March 28	Grassland	3	1	0 - 2	25.4
		3	1	2 - 4	19.0
		6	1	0 - 2	25.4
		6	1	2 - 4	18.8
		7	1	0 - 2	24.6
		7	1	2 - 4	18.8
		8	1	0 - 2	24.0
		8	1	2 - 4	19.4
April 18	Clean-cultivation	3	1	0 - 2	20.2
		3	1	2 - 4	25.9
		6	1	0 - 2	17.9
		6	1	2 - 4	25.0
		7	1	0 - 2	23.5
		7	1	2 - 4	27.2
		8	1	0 - 2	20.8
		8	1	2 - 4	23.5
April 18	Grassland	3	1	0 - 2	19.0
		3	1	2 - 4	17.4
		6	1	0 - 2	19.6
		6	1	2 - 4	17.1
		7	1	0 - 2	21.1
		7	1	2 - 4	18.2
		8	1	0 - 2	19.9
		8	1	2 - 4	17.9

APPENDIX IV (continued)

SOIL MOISTURE (continued)

DATE OF SAMPLING	TREATMENT	BLOCK NUMBER	NO. OF REPLICATE FROM BLOCK	DEPTH OF SAMPLING	PERCENTAGE SOIL MOISTURE
May 16	Clean-cultivated	3	1	0 - 2	30.5
		3	1	2 - 4	27.9
		6	1	0 - 2	28.9
		6	1	2 - 4	26.7
		7	1	0 - 2	28.5
		7	1	2 - 4	28.2
		8	1	0 - 2	28.9
		8	1	2 - 4	26.9
May 16	Grassland	3	1	0 - 2	35.1
		3	1	2 - 4	27.9
		6	1	0 - 2	35.5
		6	1	2 - 4	27.9
		7	1	0 - 2	35.1
		7	1	2 - 4	28.2
		8	1	0 - 2	34.4
		8	1	2 - 4	25.3
June 13	Clean-cultivation	3	1	0 - 2	39.3
		3	1	2 - 4	31.9
		6	1	0 - 2	40.8
		6	1	2 - 4	30.9
		7	1	0 - 2	39.7
		7	1	2 - 4	31.9
		8	1	0 - 2	37.7
		8	1	2 - 4	31.9
June 13	Grassland	3	1	0 - 2	48.8
		3	1	2 - 4	32.6
		6	1	0 - 2	58.7
		6	1	2 - 4	32.3
		7	1	0 - 2	47.9
		7	1	2 - 4	33.3
		8	1	0 - 2	45.8
		8	1	2 - 4	33.0

APPENDIX V

RAINFALL RECORDS

DAY	FEBRUARY	MARCH	APRIL	MAY	JUNE
1	...	...	..2	.39	105
2	Tr	...	...	...	.16
3	.44	...	...	...	.21
4	...	..8	...	..2	.36
5	...	..6	...	Tr	.28
6	...	...	...	...	.73
7	...	...	...	...	.58
8	Tr	...	...	...	.16
9	..	..	..	..	.66
10	..8	..3	..	..13	.50
11	..	..2	..	Tr	.27
12	.10	..	..	Tr	..1
13	.16	..	..	..	..
14	..7	..	Tr	..	..
15	..	Tr	..	..	..
16	.11	Tr	..	..2	..2
17	.19	.55	..	..	..6
18	..	..	.31	.66	..
19	.11	Tr	..2	..1	..
20	.32	..	100	Tr	..
21	..	..	.45	..9	.12
22	Tr	.48	Tr	.52	.32
23	..	.21	..	..6	..6
24	..	..2	..	..	Tr
25	..	.39	.26	.14	.59
26	..	..	.25	..4	..8
27	.36	..7	..3	..	.31
28	Tr	.12	Tr	.48	.21
29	..	Tr	Tr	Tr	.12
30	..	..	.49	.21	..9
31	..	..	..	..4	..
Total	1.94	2.03	2.83	2.81	7.76

Taken from the Meteorological Records of Grasslands Division, D.S.I.R., Palmerston North. Rainfall is recorded at 9 a.m. and entered for the previous day. Figures are given in points as recorded.

APPENDIX VI

EXPERIMENT 1 BEHAVIOUR OF NITROGEN FERTILIZERS

ADDED TO BARE SOIL

AMMONIUM-NITROGEN FIGURES (PARTS PER MILLION)

DAY	PLOT	T R E A T M E N T			
		A	B	C	D
2	1	68	769	86	378
	2	129	624	107	521
	3	87	839	88	384
	4	87	732	117	421
4	1	58	997	93	401
	2	107	779	101	329
	3	69	853	82	486
	4	55	733	105	358
8	1	63	592	78	253
	2	44	553	126	361
	3	47	561	85	333
	4	54	667	66	463
15	1	49	455	62	208
	2	51	497	57	224
	3	74	450	63	279
	4	44	383	56	260
22	1	12	295	37	106
	2	9	267	37	120
	3	18	323	32	116
	4	22	327	32	155
29	1	1	192	24	70
	2	1	210	24	90
	3	10	200	1	80
	4	2	186	14	95
36	1	5	133	22	44
	2	4	112	10	52
	3	2	133	8	36
	4	1	169	7	44
43	1	0	105	-	17
	2	0	85	-	19
	3	0	115	-	9
	4	0	110	-	33
71	1	8	25	-	9
	2	7	25	-	8
	3	8	28	-	9
	4	7	28	-	8

APPENDIX VII

EXPERIMENT 1. BEHAVIOUR OF NITROGEN FERTILIZERS
ADDED TO BARE SOIL

NITRATE-NITROGEN FIGURES (PARTS PER MILLION)

DAY	PLOT	T R E A T M E N T			
		A	B	C	D
2	1	15	18	589	295
	2	23	20	715	418
	3	21	21	626	306
	4	14	28	528	247
4	1	19	26	738	388
	2	20	38	678	291
	3	22	31	511	402
	4	7	26	705	312
8	1	21	40	425	217
	2	11	28	556	284
	3	17	23	491	239
	4	15	14	456	347
15	1	10	13	193	86
	2	6	16	185	99
	3	10	7	174	104
	4	14	18	149	86
22	1	10	18	38	35
	2	2	7	50	22
	3	9	20	59	27
	4	8	12	66	50
29	1	1	3	10	10
	2	1	3	15	10
	3	5	2	6	6
	4	2	6	8	10
36	1	1	6	11	9
	2	1	5	4	11
	3	1	6	7	9
	4	1	5	6	9
43	1	0	18	-	16
	2	0	25	-	13
	3	0	25	-	12
	4	0	21	-	24
71	1	2	25	-	6
	2	2	22	-	3
	3	2	27	-	5
	4	2	23	-	3

APPENDIX VIII

EXPERIMENT 1 BEHAVIOUR OF NITROGEN FERTILIZERS
ADDED TO BARE SOIL

SOIL pH

DAY	PLOT	T R E A T M E N T			
		A	B	C	D
2	1	4.44	4.64	4.76	6.60
	2	4.90	4.75	4.83	6.94
	3	5.20	4.84	5.00	6.05
	4	4.30	4.15	4.20	6.26
4	1	4.91	4.63	4.77	6.68
	2	5.00	4.81	4.85	6.49
	3	5.01	4.77	4.96	6.94
	4	5.12	4.87	4.84	6.76
8	1	4.97	4.86	4.96	6.32
	2	5.05	4.81	4.86	6.58
	3	5.03	4.74	4.98	6.31
	4	5.09	4.71	4.86	6.75
15	1	4.88	4.74	5.00	6.14
	2	4.90	4.74	5.06	6.30
	3	4.85	4.85	5.03	6.32
	4	4.91	4.78	5.16	6.60
22	1	5.02	5.07	5.54	6.13
	2	5.08	5.26	5.64	6.47
	3	5.26	5.14	5.56	6.24
	4	5.38	5.21	5.50	6.64
29	1	5.04	5.08	5.55	5.70
	2	4.82	5.17	5.37	6.04
	3	4.92	5.12	5.47	6.10
	4	4.98	5.10	5.50	5.72
36	1	5.20	5.37	5.68	5.84
	2	5.50	5.32	5.76	5.56
	3	5.39	5.30	5.72	5.96
	4	5.41	5.48	5.72	5.82
43	1	5.12	4.80	-	5.51
	2	5.21	4.76	-	5.41
	3	5.20	4.93	-	5.38
	4	5.20	4.90	-	5.75
71	1	5.60	4.57	-	5.88
	2	5.71	4.72	-	6.28
	3	5.64	4.50	-	5.90
	4	5.40	4.60	-	5.94

APPENDIX IX

EXPERIMENT 2 COMPARISON OF TWO RATES OF APPLICATION
OF SULPHATE OF AMMONIA TO GRASSLAND

AMMONIUM-NITROGEN (PARTS PER MILLION)

DAY	PLOT	T R E A T M E N T			
		3 cwt. per acre		9 cwt. per acre	
		0" - 3"	3" - 6"	0" - 3"	3" - 6"
4	1	93	0	382	8
	2	97	33	270	8
	3	83	10	276	2
	4	99	0	384	30
10	1	52	0	176	3
	2	19	3	191	10
	3	14	8	189	4
	4	4	9	232	3
20	1	10	4	105	2
	2	5	4	98	6
	3	6	2	84	10
	4	7	6	113	6
30	1	-	-	60	3
	2	-	-	40	4
	3	-	-	45	3
	4	-	-	35	6

APPENDIX X

EXPERIMENT 2 COMPARISON OF TWO RATES OF APPLICATION
 OF SULPHATE OF AMMONIA
 TO GRASSLAND

NITRATE-NITROGEN (PARTS PER MILLION)

DAY	PLOT	T R E A T M E N T			
		3 cwt. per acre		9 cwt. per acre	
		0" - 3"	3" - 6"	0" - 3"	3" - 6"
4	1	17	4	8	7
	2	7	18	26	7
	3	12	3	9	3
	4	3	6	6	0
10	1	7	5	6	3
	2	5	3	10	4
	3	6	5	7	6
	4	6	7	9	4
20	1	4	3	4	6
	2	3	1	3	3
	3	6	6	6	4
	4	3	2	15	3
30	1	-	-	5	2
	2	-	-	6	4
	3	-	-	4	4
	4	-	-	9	6

APPENDIX XI

RAINFALL FIGURES 1952

DAY	MAY	JUNE	JULY	AUGUST	SEPTEMBER
1	.39	105	.19	...	..2
2	...	.16	.24	...	...
3	...	.21	...	...	..1
4	..2	.36	..6	.45	...
5	Tr	.28	.29	..2	...
6	...	.73	.53	..2	...
7	...	.58	..2	..1	..3
8	...	.16	Tr	...	..2
9	...	.66	Tr	.18	...
10	.13	.50	...	.16	..1
11	Tr	.27	...	...	Tr
12	Tr	..1	...	Tr	..2
13	...	...	...	.44	..14
14	...	...	...	.15	...
15	...	...	...	...	..2
16	..2	..2	...	...	...
17	...	..6	...	...	...
18	.66	...	...	...	..8
19	..1	...	..52	...	...
20	Tr	...	Tr	...	...
21	..9	.12	...	...	...
22	.52	.32	Tr	...	...
23	..6	..6	...	...	..20
24	...	Tr	Tr	...	..5
25	.14	.59	...	...	..5
26	..4	..8	...	...	..4
27	...	.31	..1	.17	...
28	.48	.21	...	.70	..1
29	Tr	.12	...	..1	...
30	.21	..9	...	...	...
31	..4	...	...	..1	...
Total	2.81	7.76	1.86	2.32	.70